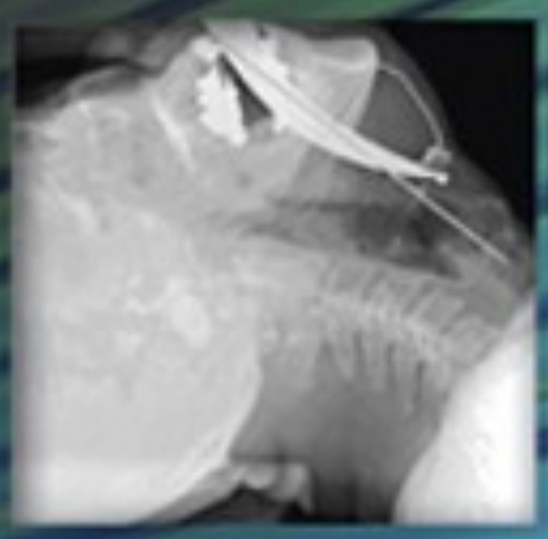
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TECHNIQUES AND TOOLS

SECOND EDITION





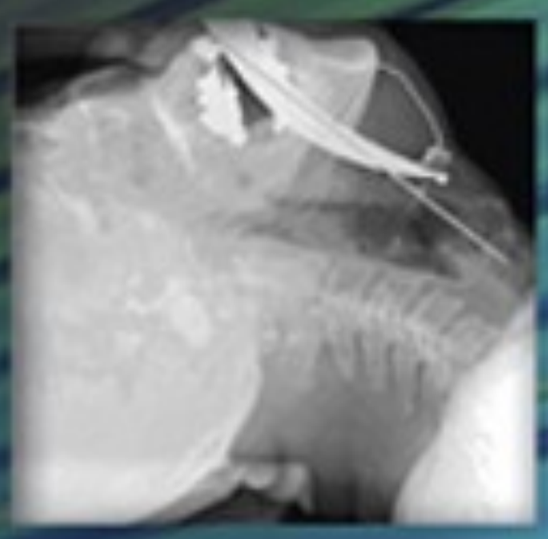
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Wolters Kluwer Health | Lippincott Williams & Wilkins

ATLAS OF AIRWAY MANAGEMENT

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Atlas of
Airway Management:
Techniques and Tools

2nd Edition

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Dedication

We dedicate this atlas to the anesthesiology residents, anesthesiologists and other acute care physicians who provide life-saving airway management to the patients at the University of Pittsburgh Medical Center hospitals.

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Preface to the Second Edition

In this, the second edition of the atlas, a number of changes will be evident. Most importantly, each chapter is now written by a separate set of authors, rather than the entire book resulting from the efforts of one individual, in order to take advantage of the variable experiences and expertise of many different practitioners. In addition to updates and revisions of existing chapters, many new chapters have been added to improve the scope and perspective of the atlas, while describing innovative new tools which have been added to the clinician's armamentarium.

Examples of specific implements that are now discussed in this edition include the Airtraq (chapter 16), a prism- and mirror-based device to improve visualization of the larynx, and the video-laryngoscopes recently released by several manufacturers, which have been rapidly and successfully adopted to cope with difficult anatomic characteristics (chapter 24). Several chapters are now included which describe unique and thought-provoking methods for evaluating a patient's physical characteristics to help predict the likelihood of difficult laryngoscopy and intubation. In addition, a chapter has been added to describe the nature and utility of non-invasive ventilation, which may reduce morbidity in certain categories of patients suffering from respiratory compromise (chapter 3). High frequency jet ventilation, a modality which may be of use in a number of different operative and critical care settings, is now considered as well (chapter 48).

Entire new sections have been added to this book, in order to provide coverage of topics which were not considered, or which were described only briefly, in the first edition. These include pediatric airway management, preexisting pathology in patients which requires special attention to airway management, specific surgical situations, diagnostic and therapeutic bronchoscopy, and management issues for the post-intubation phase of care.

In order to broaden the appeal of the book for non-anesthesia providers, and in recognition of the frequency of emergent airway management outside of the operating room, the authors of the chapters are comprised of a diverse group of practitioners, including anesthesiologists (adult and pediatric), intensivists, emergency medicine physicians and trauma surgeons. One section of the book includes chapters from critical care physicians and emergency medicine practitioners, describing the unique and challenging aspects of airway management that such physicians routinely face in the non-operating room environment.

Finally, it must be recognized that direct laryngoscopy remains the first management choice for acute care physicians in most situations, for patients requiring intraoperative care or emergent airway interventions for other reasons. Accordingly, the chapters from the prior edition which deal with airway anatomy, direct laryngoscopy and the teaching of laryngoscopy to trainees, have been expanded in scope, and re-focused in order to provide better background and instruction for more challenging cases. These now contain suggestions for improved patient positioning, use of assistants to help lift the head and avoid operator fatigue, and external manipulation of the larynx in a "two-handed" laryngoscopy technique, all of which aid in reducing the difficulty of exposing the glottis and effectively placing the endotracheal tube in the airway.

The editors:
Steven L. Orebaugh
Paul E. Bigeleisen

Preface to the First Edition

My aim in creating this book is to assist those learning to manage the airway to understand the basics—mask ventilation and optimal direct laryngoscopy—as well as to comprehend alternative techniques for situations in which direct laryngoscopy is difficult, or cannot be utilized. There is an ever-expanding array of airway tools, of many different types, covering a spectrum of costs and degrees of complexity. It behooves the provider to understand how different techniques work and when they are effective so that two or three alternatives to laryngoscopy can be chosen, learned, and practiced. Because I initially trained in emergency medicine, then critical care medicine and, finally, anesthesiology, I have experienced airway management from several different viewpoints. I have attempted to share these perspectives in this atlas.

Many fine airway management books exist, ranging from small handbooks to expansive texts. Some of these texts suffer from a lack of instructive illustration. In an attempt to complement them, this atlas was created, and thus provides more illustration than text. In order to make the relationships between anatomy and airway management tools clear, a large variety of illustrations is presented, including mockups in cadaver specimens, photos of airway management in the clinical setting, simulated airway management scenarios, and photographs of the airway utilizing video laryngoscopes and fiberoptic bronchoscopes.

Most of the atlas is dedicated to defining and illustrating the many devices and techniques that exist for endotracheal intubation when direct laryngoscopy is difficult or undesirable. These topics are covered in eight parts, in the following areas: adjuncts to direct laryngoscopy, blind intubation techniques, light-guided intubation, retrograde intubation, fiberoptic techniques, emergency ventilation techniques (supraglottic and infraglottic), combinations of techniques, and emergency surgical airways. Within each section are one to five chapters detailing the devices or procedures that fall under that heading.

The first portion of this atlas is intended to cover basic airway management, including airway anatomy, bag-mask ventilation, direct laryngoscopy, and pharmacology relevant to endotracheal intubation. While the purpose of this book is to provide information on management of the adult airway, a chapter on the pediatric airway is included. When applicable, references to pediatric airway management are made in the various chapters covering implements or techniques. In the second section, difficult airway management is explored, including the epidemiology of this life-threatening problem in elective cases in operating room, and in more emergent settings. Decision-making in the face of recognized or potential difficult airways, due to anatomy, disease, or obesity, for example, is discussed, as well as training of physicians, students, and nurses at the University of Pittsburgh utilizing high fidelity human simulation. In the last chapter of this section, a survey of anatomic and pathologic causes of difficult airway management is presented.

Brevity and an organized format for the text are as important in an atlas as are the illustrations themselves. For this reason, the chapters covering specific tools or techniques are arranged according to the following template: The concept is presented, followed by a discussion of existing evidence supporting the use of the intervention. Next, the preparatory steps for the procedure are listed, followed by a description of the steps necessary to carry out the procedure itself. Following this is a listing of elements of practicality, affordability, portability, familiarity, complexity, and other concerns which impact the ability to integrate the tool or technique into medical practice. Finally, indications, contraindications, and complications of the intervention are noted. A series of illustrations is provided, showing the tool(s) involved, how these are placed in the patient (demonstrated in a cadaver specimen), and clinical photos, or simulations, of the device in use. When appropriate, step-by-step sequential illustrations show the progression of the procedure.

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PART I

Routine Airway Management

CHAPTER 1

Anatomy of Direct Laryngoscopy

James Snyder and Steve Orebaugh

ORIENTATION

X-rays in supine and sniffing positions with corresponding illustrations help convey anatomy dynamics as well as details (Fig. 1-1). Direct laryngoscopy (DL) requires displacement above a line of sight (LOS) between the upper teeth to the glottis, of the hyoid bone, tongue, and epiglottis. Hyoid bone movement forward depends on adequate slack in the stylohyoid ligament (SHL). The tongue when flaccid acts likes a viscous mass. Control of the epiglottis depends on the type of blade used.

ANATOMY OF THE MOUTH AND TONGUE

The most obvious oral impediments are the teeth and tongue (Fig. 1-2). The tonsillar pillars and fauces are visible on either side as they course from the soft palate to the base of the tongue, in effect creating a tubular inlet to the oropharynx.

Laryngoscopy from the right corner of the mouth can bypass the bulk of the tongue, shorten the distance to the larynx, and lower (improve) the angle of approach to the glottis, and has been successful in many cases where alternatives failed. Practice is required to maintain orientation.

The Dorsal Tongue

The posterior third of the dorsum of the tongue looks backward and contains numerous submucous adenoid collections and lymph follicles called the lingual tonsil. Hypertrophy of the lingual tonsil has been described as a common and important cause of unpredicted difficult intubation where the epiglottis cannot be lifted from a dorsal approach over the tongue (Fig. 1-3).[1] Hypertrophic lingual tonsils impair tongue displacement and are prone to bleed with minimal trauma. The potential for hemorrhage should encourage early consideration of paraglottic straight blade technique.[2]

The Tongue is a Dome of Muscle

The tongue is rooted in and rises up from two roughly concentric U-shaped bones, the mandible and hyoid (Fig. 1-4). The bulk of the tongue is the intrinsic genioglossus muscle, which arises from the mandible anteriorly and extends fibers to the hyoid bone posterior (Fig. 1-4A). Laterally the tongue is secured to the hyoid by a vertical sheet of muscle, the hyoglossus (Fig. 1-4B). The floor of the mouth is predominantly formed by the mylohyoid muscle, which slopes from attachments around the mandible to form a midline raphe anteriorly and to the hyoid bone posterior (Fig. 1-4C). This arrangement is comparable to the levator ani that forms the floor of the pelvis.[3]

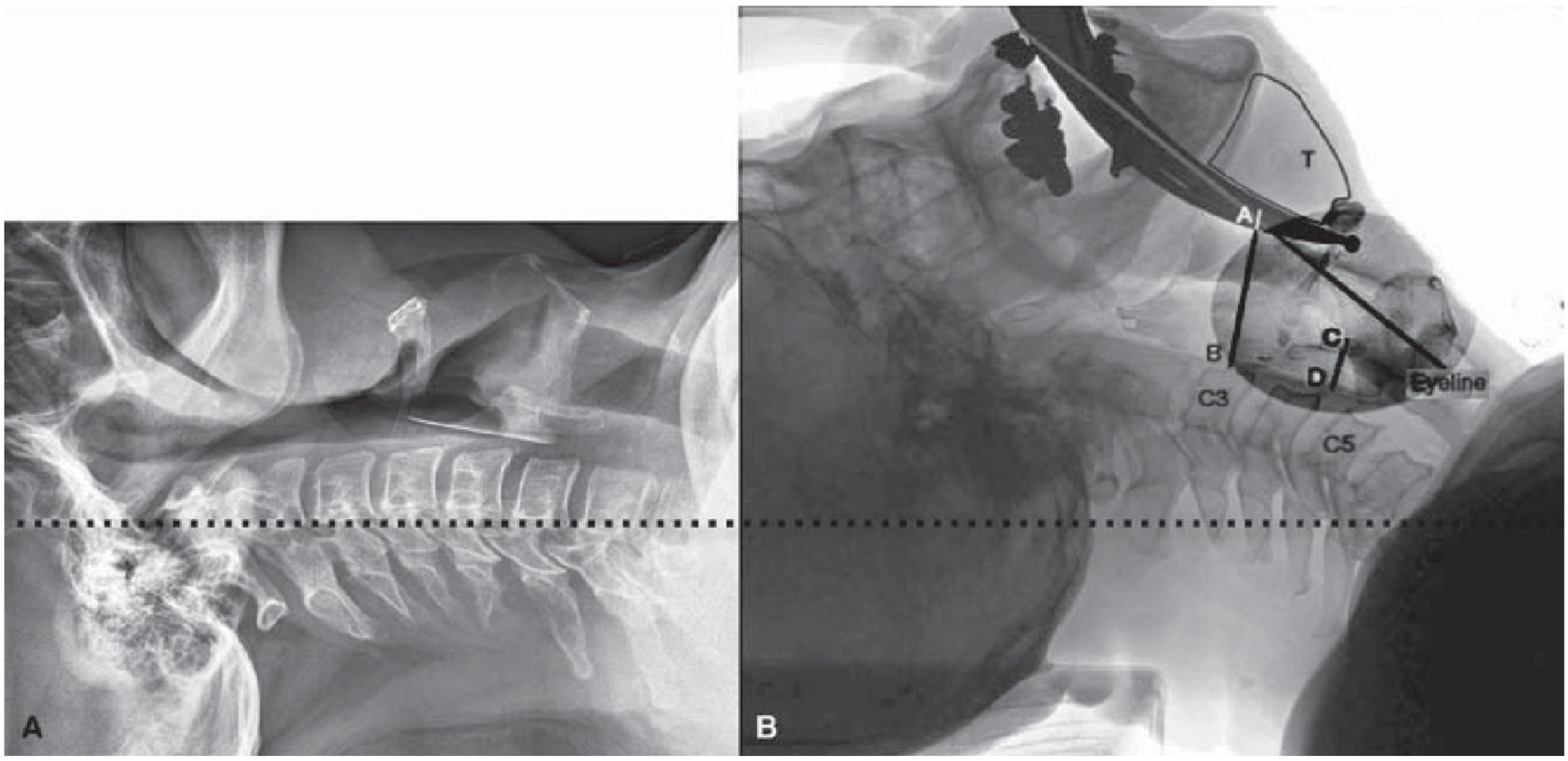
Muscle Tone and the "Peardrop" Phenomenon

Tongue flaccidity and adhesion of the blade to the tongue complicate finding and controlling the epiglottis. Lifting the blade before each advance can break adhesion. Steps are kept small to avoid bypassing the epiglottis. Loss of lingual muscle tone requires additional attention. The tongue has a globular shape when the mouth is closed and muscle tone is normal (Fig. 1-4A). With loss of muscle tone, the tongue is easily distorted dorsally by contact with the blade as it is being inserted, and the tongue and epiglottis are readily pressed against the posterior pharyngeal wall (Fig. 1-5).

In code situations, the tongue may be found "slurred" up against the palate as well as the posterior pharyngeal wall, impairing bag-mask-ventilation (BMV) as well as laryngoscopy. Passing the blade between the blade and palate can cause trauma to soft tissues. A gauze pad enables grasp of the flaccid tongue by its broad tip, to be pulled forward and then maintained forward by continuous positive airway pressure with BMV or by the laryngoscopy blade.

Larynx and Epiglottis

The larynx is a 4 cm long structure below an almost 2 cm inlet (Fig. 1-6). It overlies the 4th, 5th, and 6th cervical vertebra in adult males, higher in females and children.



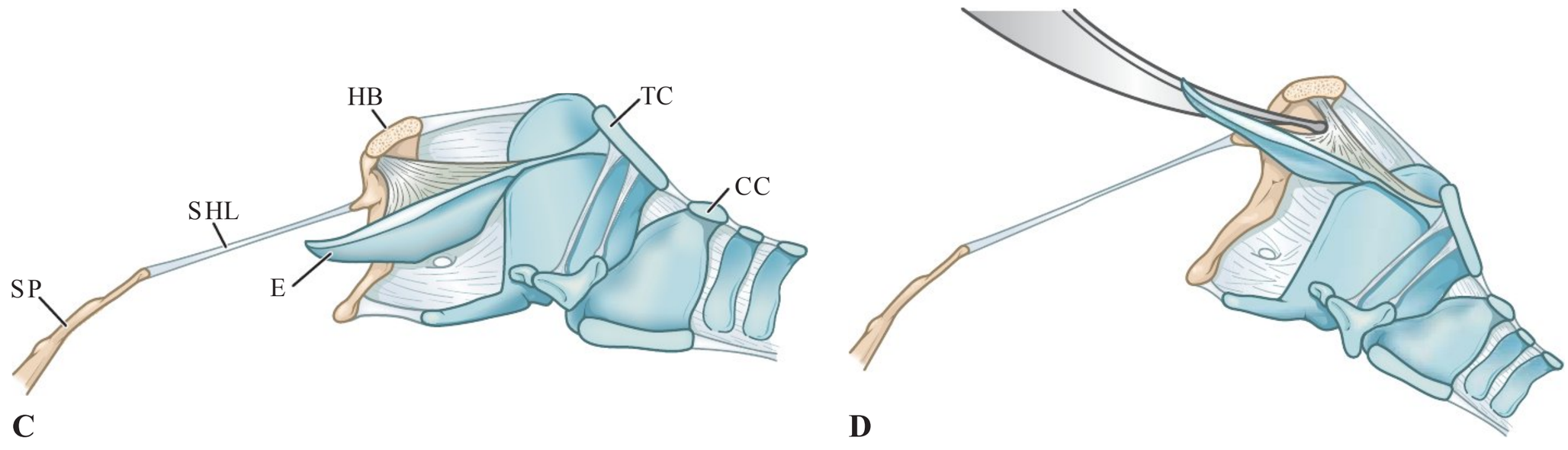


FIGURE 1-1 X-ray laryngoscopy supine and during DL in sniffing position (aligned at dorsal C6), and corresponding illustrations. **A:** In the neutral position, the hyoid bone (HB) is dorsal to the thyroid cartilage (TC) and therefore also to the glottis. The SHL functions as a cable by which the larynx is suspended from the styloid process (SP), which can be seen in **A**, just behind the anterior arch of the atlas. The posterior extensions of the hyoid bone and lateral walls of the thyroid cartilage abut the posterior pharyngeal wall. **B:** During DL in the sniffing position (head elevation and a-o extension), the entire larynx is rotated forward. Both the hyoid and thyroid cartilage are lifted forward from the pharyngeal wall. In particular, notice the hyoid is lifted anterior to the glottis (compare **C** and **D**). Because LOS requires the hyoid forward of the thyroid cartilage, it appears that release of tension in the SHL may be a mechanism by which head elevation facilitates DL. (**A** modified from Fuller MJ http://www.wikiradiography.com/page/Lateral+ Soft+ Tissue+ Neck+ for+ Foreign+ Body, Case #1with permission;**B** modified from Nishikawa K, Yamada K, Sakamoto A. A new curved laryngoscope blade for routine and difficult tracheal intubation. *Anesth Analg*. 2008;107:1248–52 with permission.)

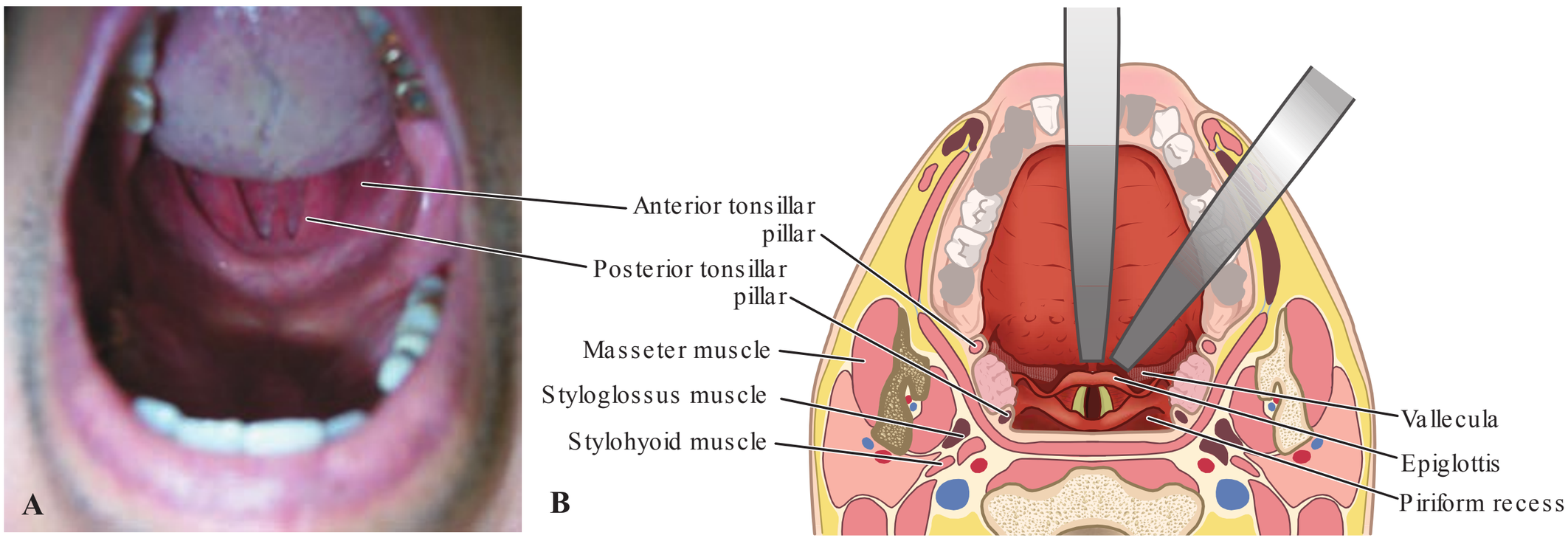


FIGURE 1-2 View into mouth.**A:** The anterior and posterior tonsillar pillars and palatine tonsil form an isthmus between mouth and pharynx. Note the open space cephalad, under the palate. **B:** Laryngoscopy with a curved blade usually is over the right dorsum of the tongue, directed to contact its broad leading edge against the midline fold of the HEL to "flip" the epiglottis up against the blade (M).[24] Laryngoscopy from the right corner of the mouth and along the base of the tongue (paraglossal) with the straight blade often enables glottal view not possible with a curved blade, as it bypasses the bulk of the tongue, shortens the distance to the larynx, and improves the angle of approach to the glottis (P). See chapter on Direct Laryngoscopy. (**B** revised from Netter FH. *Atlas of Human Anatomy*. 4th ed. Philadelphia, PA: Saunders/Elsevier; 2006 with permission.).

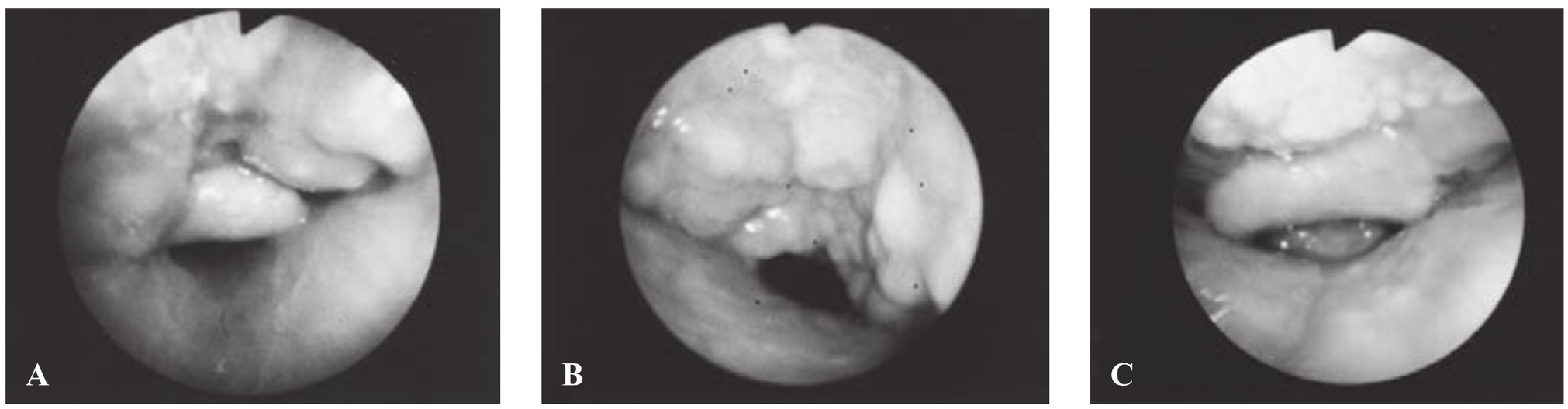


FIGURE 1-3 Hypertrophic lingual tonsils (in the top 1/3 to ½ of each example above) can extend to or cover the tip and lateral edges of the epiglottis (in the center). Lower part of each image is the soft palate. Manipulation of the friable tissue can cause copious bleeding (Modified from Ovassapian A, Glassenberg R, Randel GI,The unexpected difficult airway and lingual tonsil hyperplasia: a case series and a review of the literature.*Anesthesiology*. 2002;97(1):124–132 with permission.)

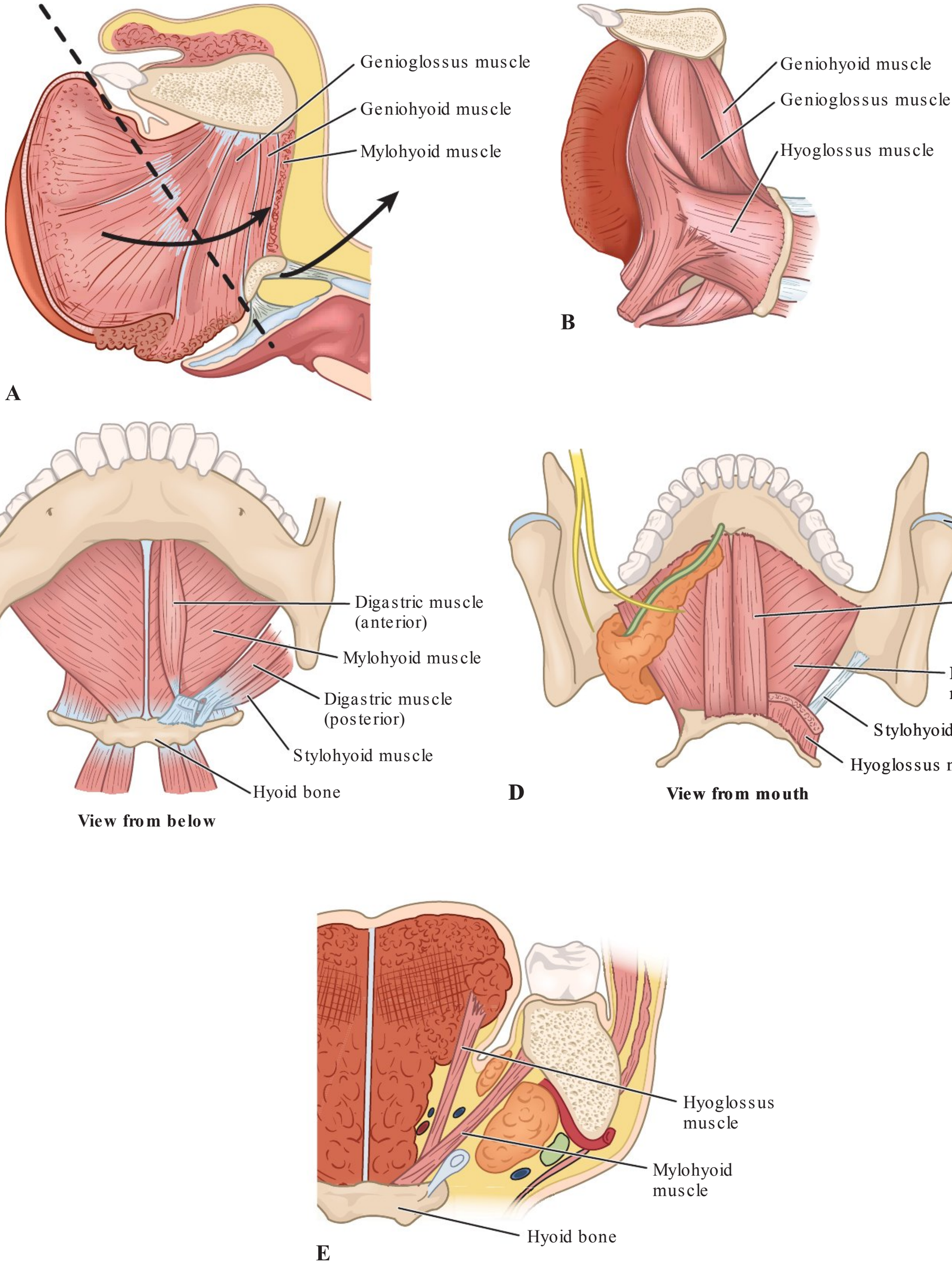
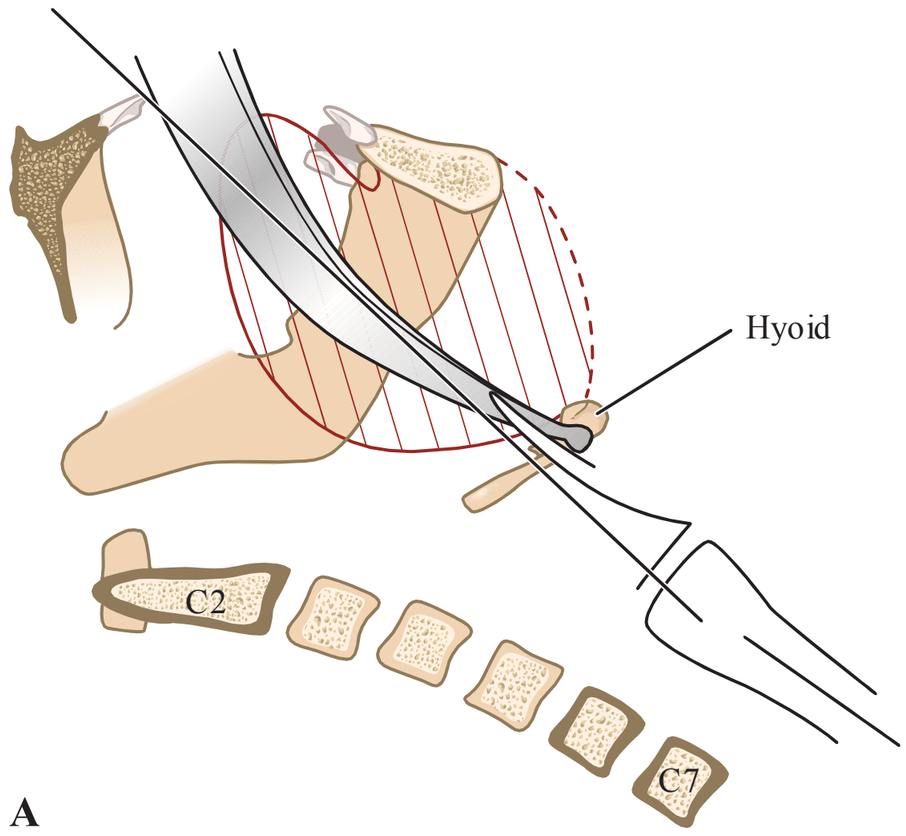
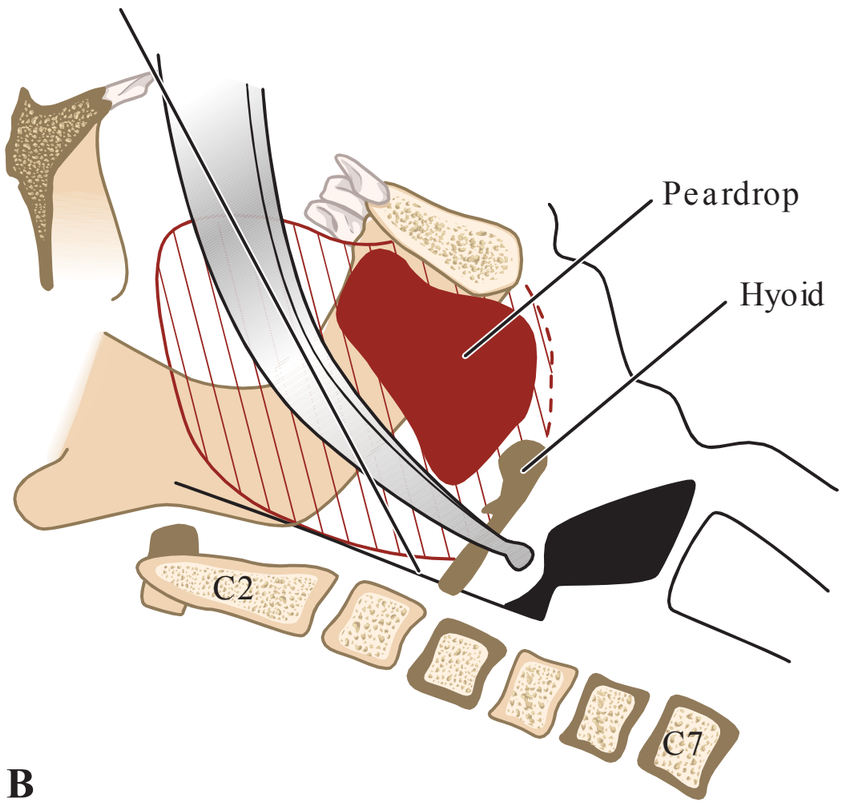


FIGURE 1-4 Muscles of the tongue. The hyoid normally is palpable at the junction of the neck and chin **(A)**. DL in the midline requires the tongue, epiglottis and hyoid displaced *(arrows)* across a line from the teeth to the glottis *(dashed line)*. Although limited by dentition and elasticity of the mouth, blade insertion from the corner of the mouth may provide a better angle *(dotted line)*. A-o extension (compare **A** and **B**) lengthens the space into which the tongue is displaced and stretches the tissues of the submandibular space. Displacement of the tongue requires stretch of the floor of the mouth (anterolateral mylohyoid **(C, D, E)** and midline geniohyoid **(A, B)**, and of the suspending elements: the palatoglossus, styloglossus, stylohyoid, digastric muscles, and tenses the SHL. Ease of passing the endotracheal tube from the right side of the mouth or adjacent to the base of the tongue (paraglossal) is strongly influenced by whether molars are present (E).





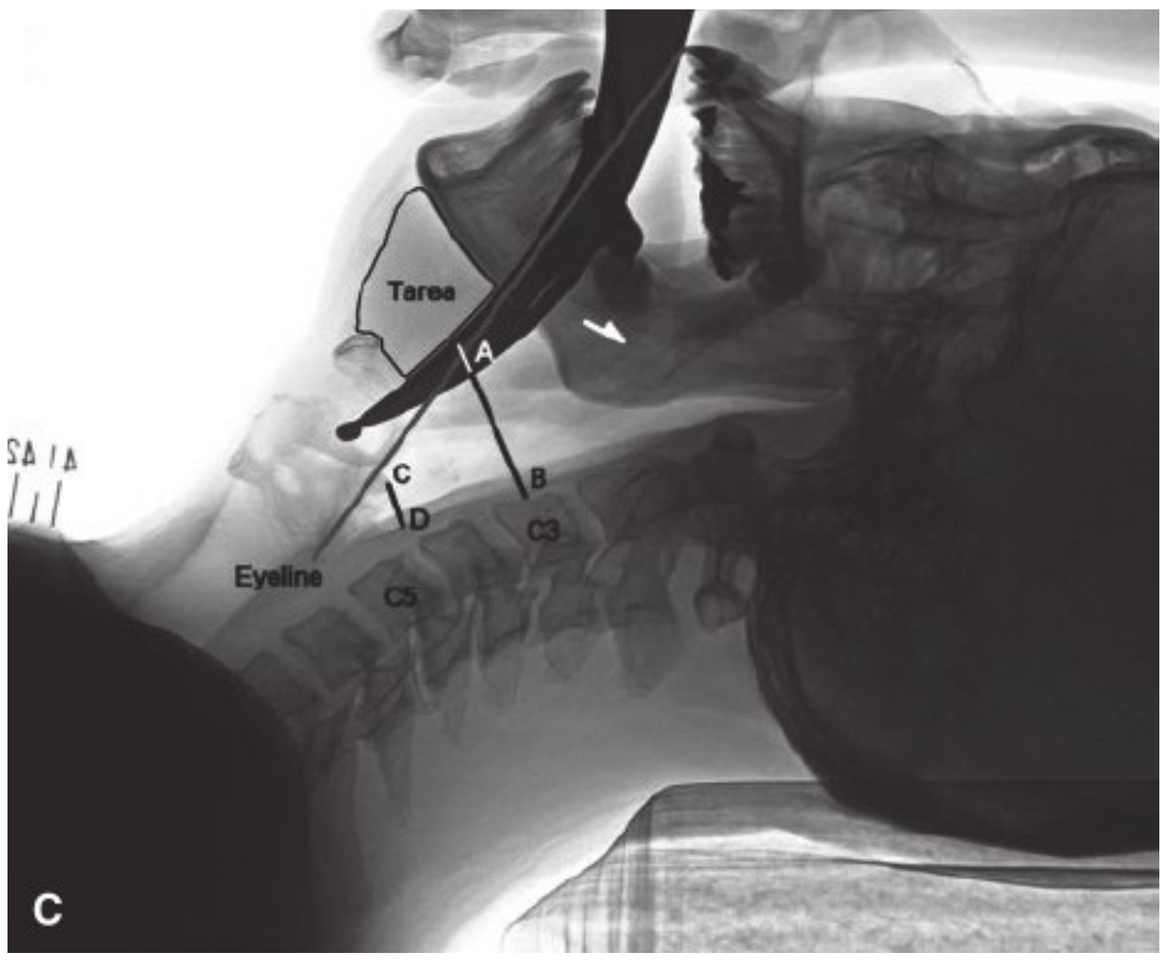
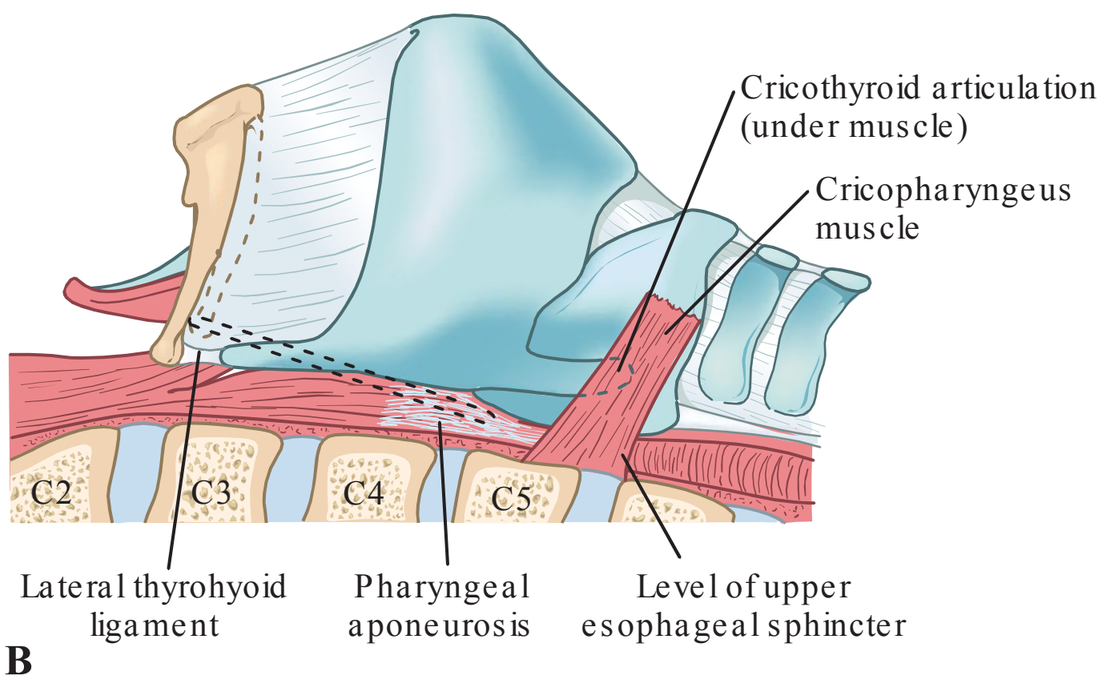


FIGURE 1-5 X-ray laryngoscopy: normal vs. the "peardrop phenomenon". **A:** The diagram shows the expected position of the laryngoscope blade *(shaded)* relative to the tongue *(cross-hatched)* in the sniffing position. Tongue is shown dorsal to the blade because the blade displaces the tongue laterally as well as forward. The blade tip reaches to just behind the hyoid. The dashed line represents the anterior delineation of the tongue. **B:** The "peardrop" phenomenon. The tongue has "slurred" dorsally, to a shape called peardrop by Horton et al.[23] The blade tip is beyond the hyoid and held well back from it by the tongue, which is trapped by the blade. **C:** X-ray laryngoscopy of the peardrop phenomenon. (**A** modified from Horton A, Fahy L, Charters P. Factor analysis in difficult tracheal intubation: laryngoscopy-induced airway obstruction. *Br J Anaesth*. 1990;65:801–805 with permission; **C** modified from Nishikawa K, Yamada K, Sakamoto A. A new curved laryngoscope blade for routine and difficult tracheal intubation. *Anesth Analg*. 2008;107:1248–52 with permission.)





B

FIGURE 1-6 Laryngeal skeleton: Lateral X-ray and corresponding illustration. The greater horns of the hyoid bone (HB) and the lateral walls of the thyroid cartilage (TC) abut the posterior pharyngeal wall, forming rigid struts for the upper larynx. A piece of shellfish *(arrow)* is caught in the piriform recess above the upper esophageal sphincter, which is dorsal to the lower third of the dorsal plate of the cricoid cartilage (CC). The thyroid cartilage is suspended from the hyoid on three sides by a flexible sheet-like ligament, the thyrohyoid membrane. **A:** X-ray: Airspace *(dark)* outlines the tongue, valecula, and laryngeal inlet and the trachea below the thyroid cartilage. The valecula is the dark loop under the hyoid between the tongue and epiglottis. **B:** Surface of laryngeal skeleton. The thyroid cartilage is secured at its inferior horn by an articulation to the cricoid cartilage, which restricts their movement primarily to flexion and extension. In this neutral to extended position, the hyoid is dorsal to thyroid cartilage due to tensed SHL ligament, and the cricothyroid articulation is extended, stretching the cricothyroid membrane. (**A** modified from Fuller MJ http://www.wikiradiography.com/page/Lateral+Soft+Tissue+Neck+for+Foreign+Body, Case #1 with permission.)

It is suspended from the hyoid bone via a flexible sheet of ligament, the thyrohyoid membrane (Fig. 1-6). The hyoid bone is secured dorsally to the skull via the SHL. The hyoid and thyroid cartilage are open-ring structures that form the anterior wall of the lower pharynx. The laryngeal skeleton can swing well forward of the posterior pharyngeal wall, because it is secured to the somatic skeleton primarily by the SHL above and the cricopharyngeus muscle at C6. The upper esophageal sphincter is formed from fibers of the cricopharyngeus muscle, which extends from one side of the cricoid arch to the other; the cricoid cartilage is secured to the posterior pharyngeal wall by the tone of the cricopharyngeus muscle.[3,4]

The Larynx: Operator and Alternative Views

The DL learning curve has been substantially altered by Levitan's development of a video system to capture the operator's view and his promotion of learning the operator perspective in advance of clinical practice. Although published emphasis relating to technologic development is largely focused on indirect laryngoscopy, we ascribe to Levitan's[5–10] work much of our reorientation to the dynamic three-dimensional nature of DL mechanics related below.

Often the operator's view is experienced and imaged as follows.

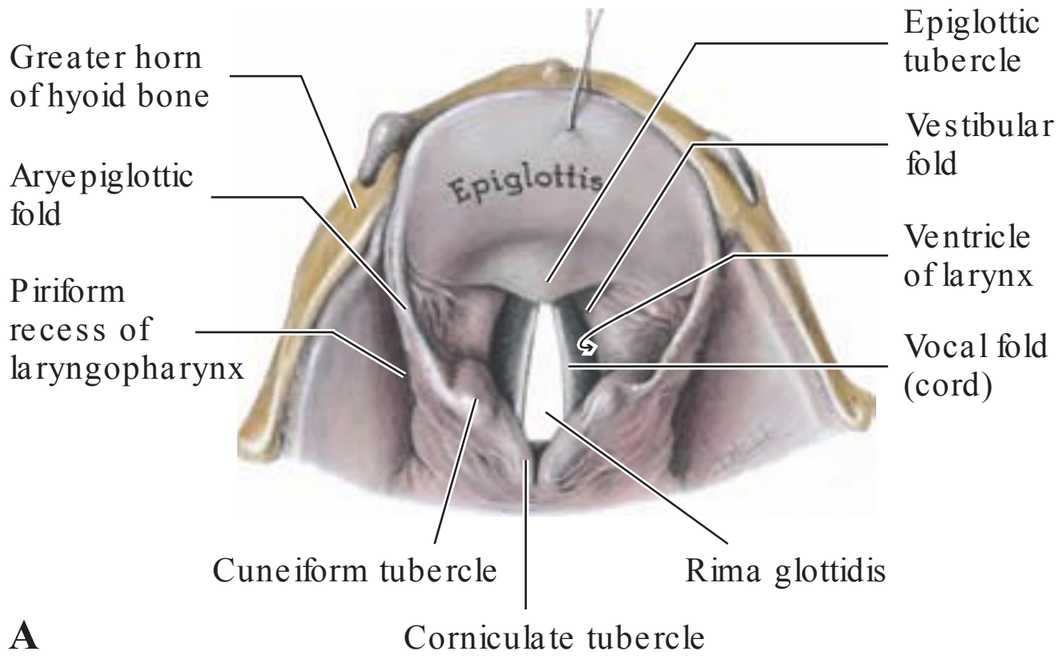
Laryngeal Inlet and Epiglottis Control

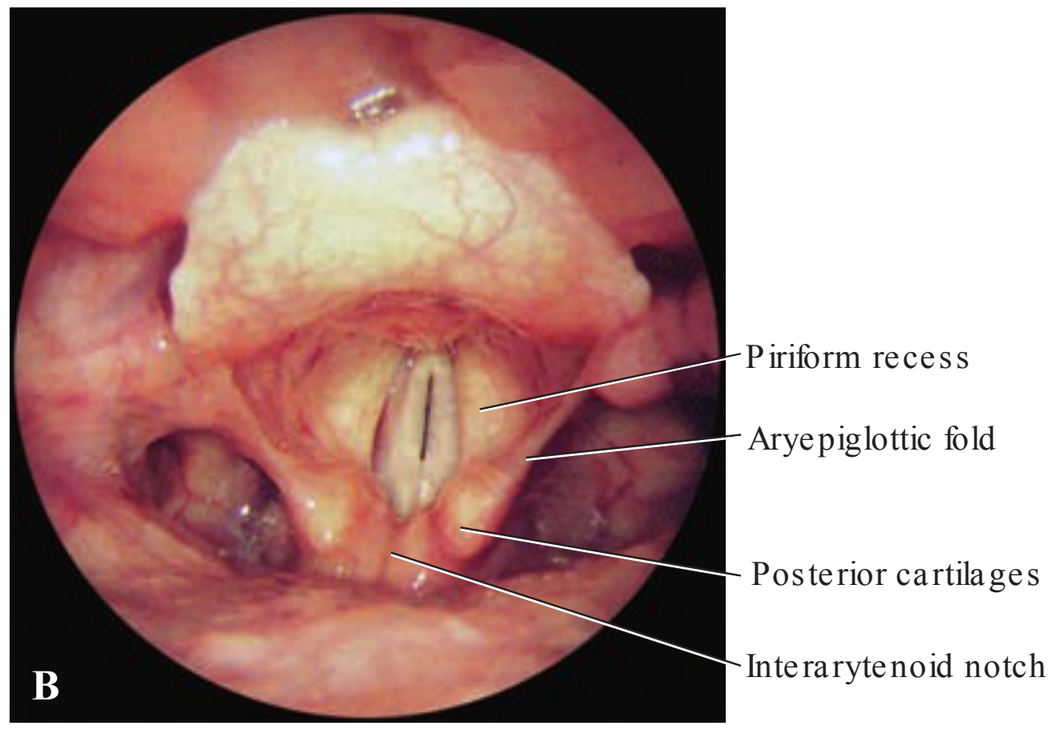
The laryngeal inlet has considerably more depth than is apparent to the operator or in photographs or training diagrams (Figs. 1-6–1-8). It may be helpful to visualize a "Robin Hood hat" obscuring the glottis (Fig. 1-9).

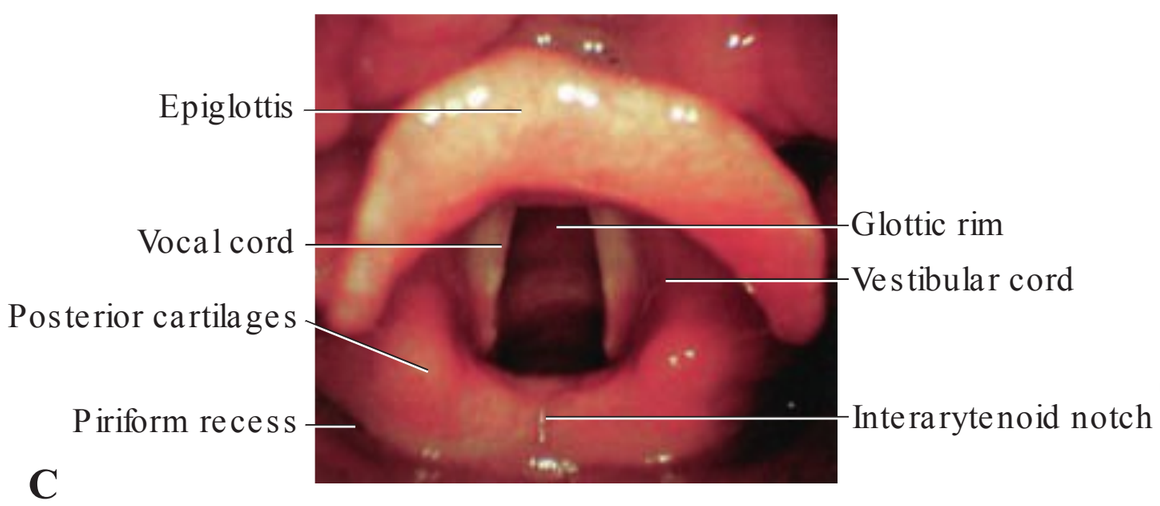
Leveraged Elevation of the Epiglottis with the Curved Blade: The "EpiFlip"

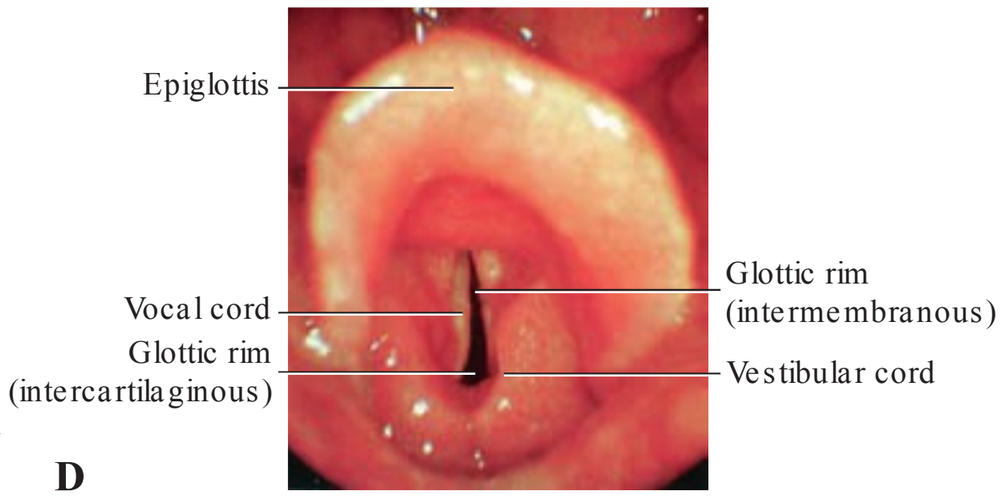
Often curved blade placement is described imprecisely, such as "in the vallecula," or "against the hyoepiglottic ligament." Dissection makes clear and blade-based video routinely confirms there is a "sweet spot" where pressure causes a leveraged upward movement of the epiglottis—a "flip." The sweet spot, on the mid-portion of the median fold of the hyoepiglottic ligament (HEL), cannot directly be seen in DL.

In DL, the optimal point is located by quickness of visible epiglottis response to small oscillations of blade tip pressure. Pressure oscillations may be generated by moving the blade or by quick gentle pressing movements externally against the thyroid cartilage, or sometimes the









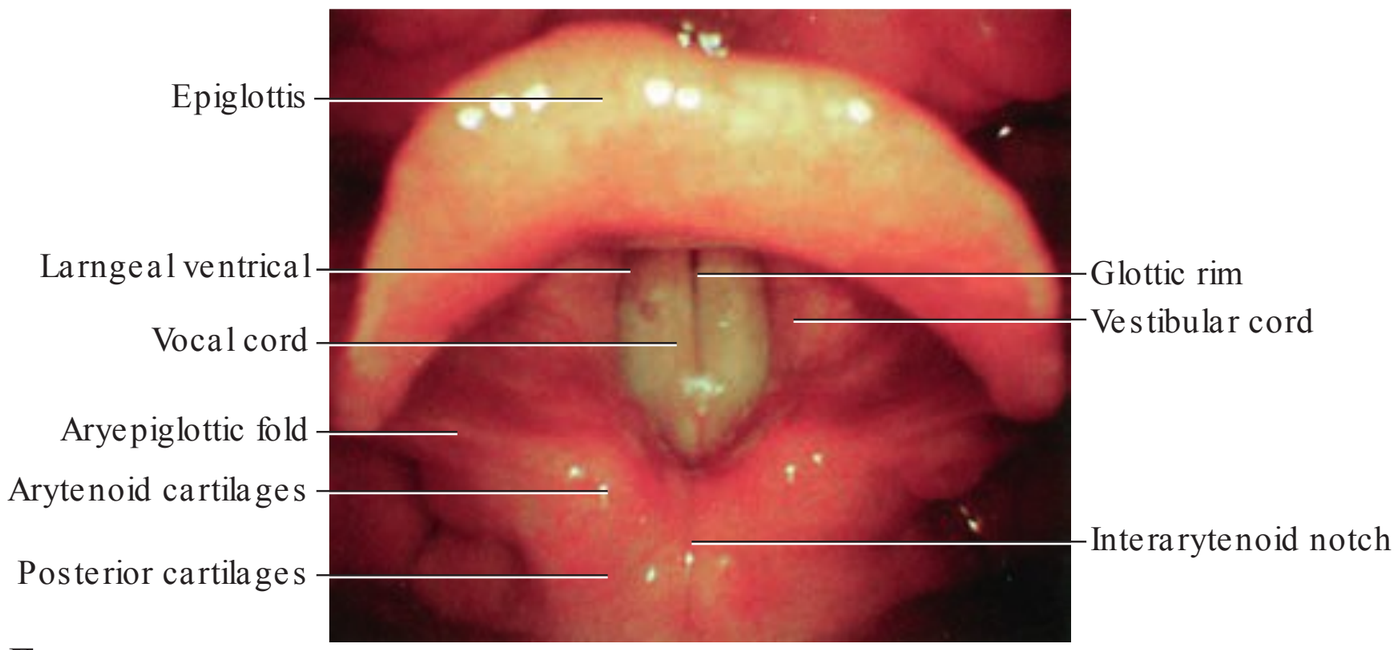


FIGURE 1-7 Operator views of the glottis convey less depth than must actually be traversed. **A:** Illustration of anatomy from operator perspective. **B:** The elevated epiglottis is the broad light band (clock position 10 to 2) distorted by proximity to the lens. The larynx is lifted forward, exposing the piriform recess behind. Advance of the ET *(circle)* toward the glottis can be impaired by "snagging" on prominent posterior cartilages, dislocation of which is a relatively common injury. **C, D, E:** A slightly more edematous larynx in positions of inspiration, phonation and whisper.

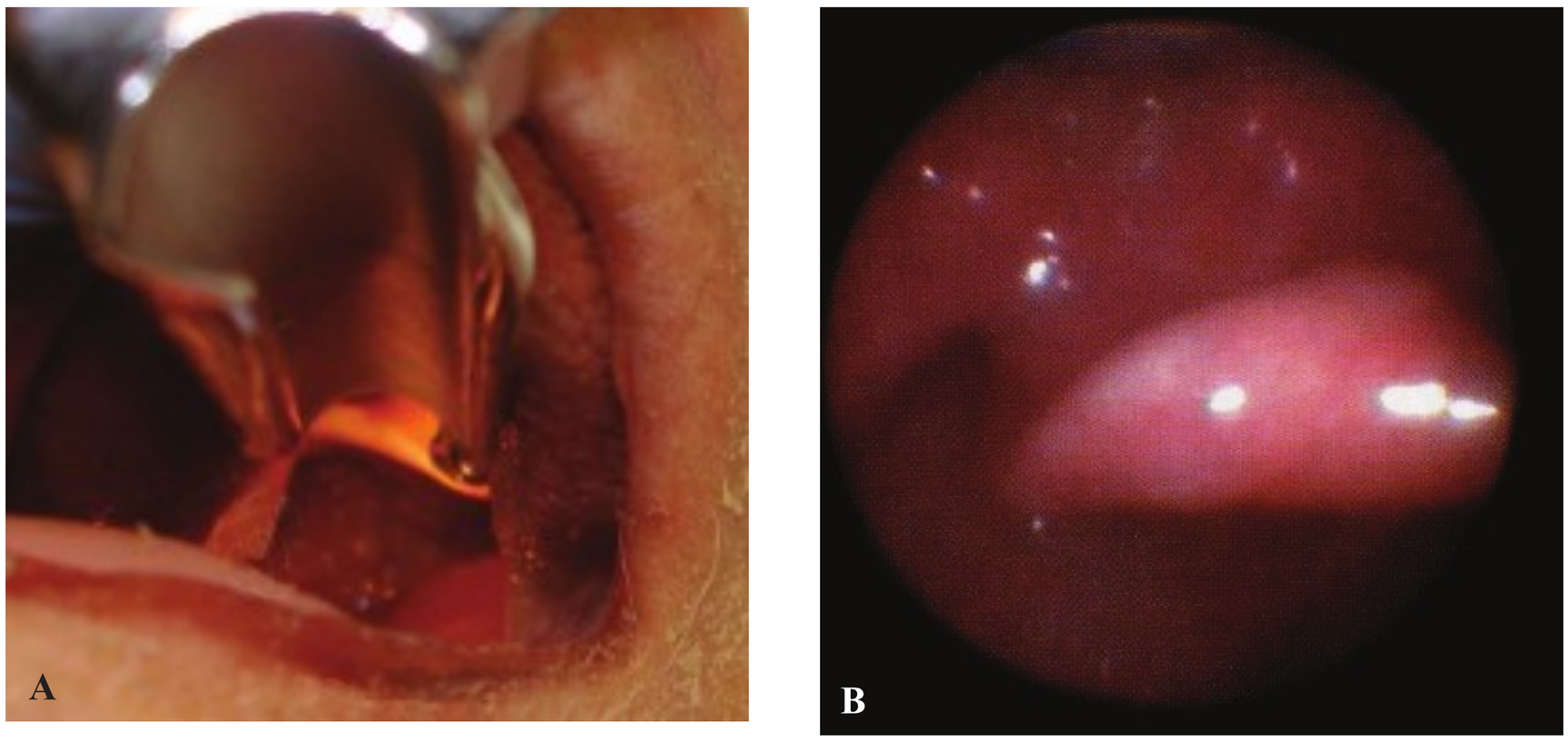


FIGURE 1-8 Suboptimal elevation of the epiglottis. Excellent control of the tongue may provide only a clear view of the epiglottis, elevation of which requires a completely different understanding. **A:** Viewed with a straight blade from the right corner of the mouth, a bright epiglottis tip shadows the left posterior cartilage. The "sweet spot" on the HEL is difficult to locate with the narrow tip of the Miller blade, shown, compared to broader blade tips such as the Macintosh or Henderson. **B:** The tip of the epiglottis is curving up toward the lens on a blade-based system. The irregular mucosal surface above the epiglottis suggests the blade tip has not advanced past the base of the tongue. (Source = Orebaugh 1st ed?)

hyoid. Pressing externally can ascertain positioning more effectively than moving the blade tip. Also external pressure may facilitate movement of the "sweet spot" toward the blade tip rather than depending only on exploration with the blade.[8] Understanding various blade tip locations that cause a sluggish and inadequate epiglottis lift are a basis for repositioning trials (Fig. 1-10).

Bimanual Laryngoscopy: One Term for Two Valuable Techniques

The term bimanual laryngoscopy has been applied to two techniques.[11] Bimanual laryngoscopy originally referred to routine use of the right hand to move the head through a range of positions, as described by Murphy: ". . .the sniffing position is a starting position only…make it dynamic. Use your right hand behind the head to lift it, *flex and extend the head on the neck*, *rotate it left and right* as needed to bring the target into view. Once the best view is obtained, have an assistant hold the head in this position."[12]

The operator using his right hand for external laryngeal manipulation (ELM) is the other technique called bimanual laryngoscopy. The high value of operator ELM for novices as well as experienced practitioners justifies routine early employment.[10,13,14] For novices, incidence of no visible glottis was reduced from 11% to zero, and when the POGO was less than 20%, the average improvement in POGO was greater than 50%.[8] Programmed external manipulation by an assistant (Backward, Upward, Rightward Pressure, BURP) is substantially less effective.[15]

Usually the two forms of bimanual laryngoscopy are considered alternatives, but voice-controlled head elevation by an assistant allows a very efficient combined application. The assistant lifting before or soon after blade insertion minimizes left hand lifting force and frees the right hand to ELM and if necessary fine-tune the assistant's head lift.

ANATOMY OF POSITIONING FOR DL

The mechanisms by which axial positioning influences DL have not been welldefined.[16,17] Pioneer laryngeal surgeon Chevalier Jackson[18] is often noted to have recommended "the head in full extension." Anesthesiology literature transitioned gradually away from extension to favor a "sniffing position"—mild elevation of the head with atlanto-occipital extension, which is detailed below. Recent articles have acknowledged reports of benefit from head elevation, including "maximal" head elevation.

Various observations conclude flexion can facilitate DL in difficult cases. Studies in anesthetized patients led Hochman et al[19] to recommend "flexion of both the head and neck (chin to chest) [as] the ideal position to intubate the patient whose glottis is difficult to observe by means of routine positions." Levitan observed that in each of nine cadavers glottic exposure was improved by raising the head from flat to moderate to maximal

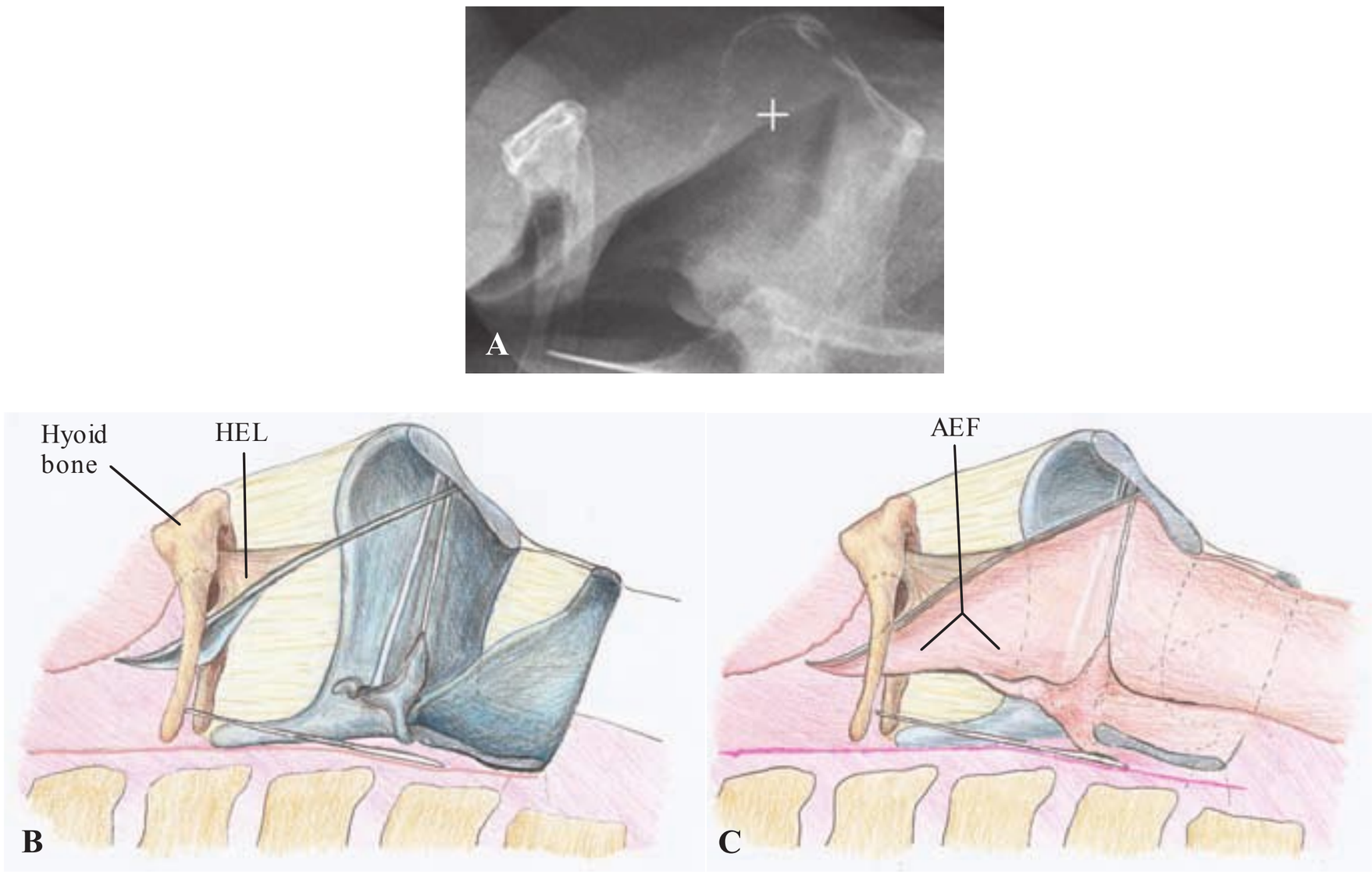


FIGURE 1-9 The laryngeal inlet as an elongated "Robin Hood hat with tipper and ear-pads." **A:** Lateral illustration "cut away" to show multiple levels. **B:** X-ray (from Figs.1-1A and 1-6). **C:** During direct laryngoscopy. The epiglottis (E) forms the entire top surface of the hat, including a long brim that typically hides the glottis/face at the back of the hat. The hyoid bone forms a crude lifting handle above the brim. A tear-shaped shadow under the hyoid is formed by the median fold of the HEL. Pressure against the HEL "tips" the hat brim up. The lateral walls of the inlet are the aryepiglottic folds (AEF)—delicate curved lines from the tip of the epiglottis to blurred "earpad" densities, which are the arytenoid, or posterior, cartilages.

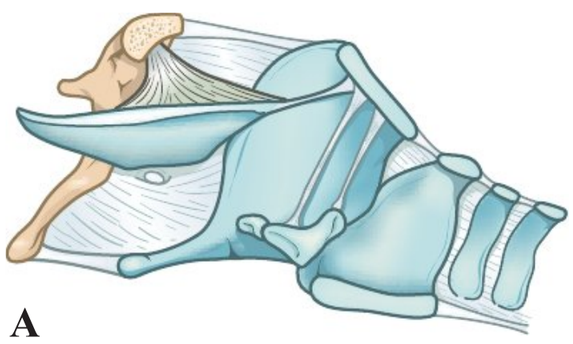
elevation. Average POGO improved from 31% to 64% to 87%.[4] By the addition of maximal head elevation and ELM, Schmidt et al were able to expose at least the posterior cartilages in all but two in a series of 1,500 OR cases.[20]

Notably, Chevalier Jackson completely reversed his initial recommendation for extension. He later affirmed, "Overextension of the patient's head is a frequent cause of difficulty. *If the head is held high enough* [even a-o] extension is not necessary…" (Fig. 1-11).[21] Other strongly pro-flexion/head elevation comments are in the [Web access]. Jackson's lifelong practice of continuous left hand laryngoscopy during all his laryngeal procedures conferred great sensitivity to which positioning would provide optimal laryngeal exposure.

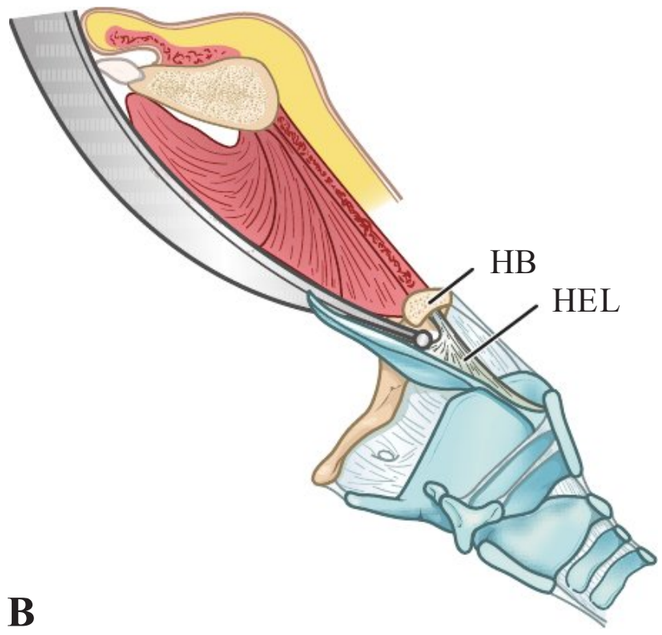
Palpation of Flexion Effect on the Antero-Posterior Relationship between the Hyoid Bone and Thyroid Cartilage

Palpation of this dynamic relationship is helpful to convey its prominent effect. To do so, hold the index and third finger on the anterior prominences of the hyoid bone and thyroid cartilage of a slender person. The hyoid might be more palpable by its sides, above the thyroid cartilage. The subject should keep his head horizontal while moving it fore and aft in an exaggerated way, akin to a pigeon when walking (Fig. 1-12). Movement backward comprises neck extension and a-o flexion, and movement forward is cervical flexion and a-o extension. With head movement backward, the hyoid can be felt to move posterior to the thyroid cartilage, and with forward movement, the hyoid can be felt to move in front of the thyroid cartilage. Because the tongue and epiglottis are hyoid-based and the glottis is in the thyroid cartilage, this palpable movement suggests how flexion might facilitate DL.

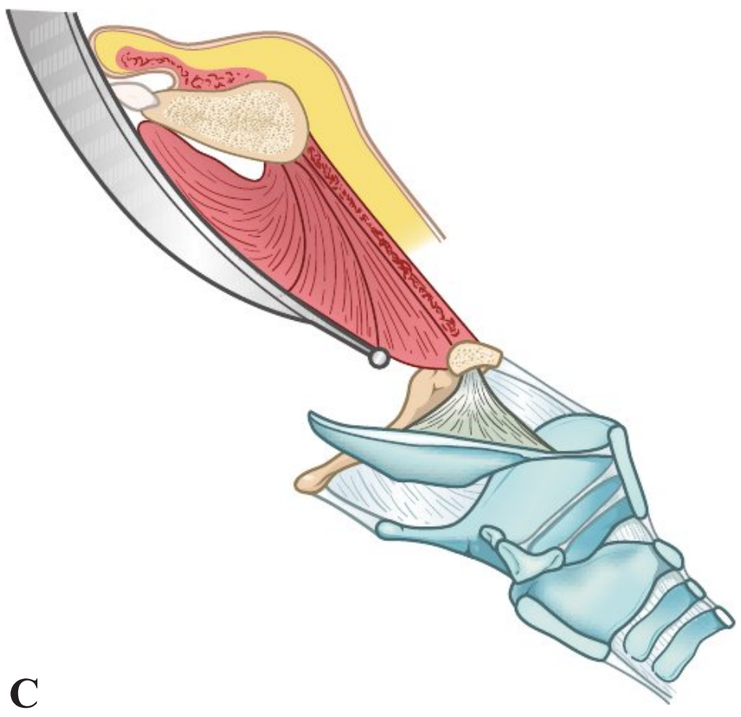
Clearly, the anatomy of the airway is complex, and its relevance to airway management involves both static and dynamic aspects. The more dynamic characteristics, related to optimal positioning, appropriate placement of the laryngoscope blade, lifting forces, and the bimanual approach to laryngoscopy, are considered in more detail in Chapter 5, "Technique of Direct Laryngoscopy." Innervation of key airway structures is discussed in Chapter 8, "Regional Anesthesia Blocks for Awake Intubation."



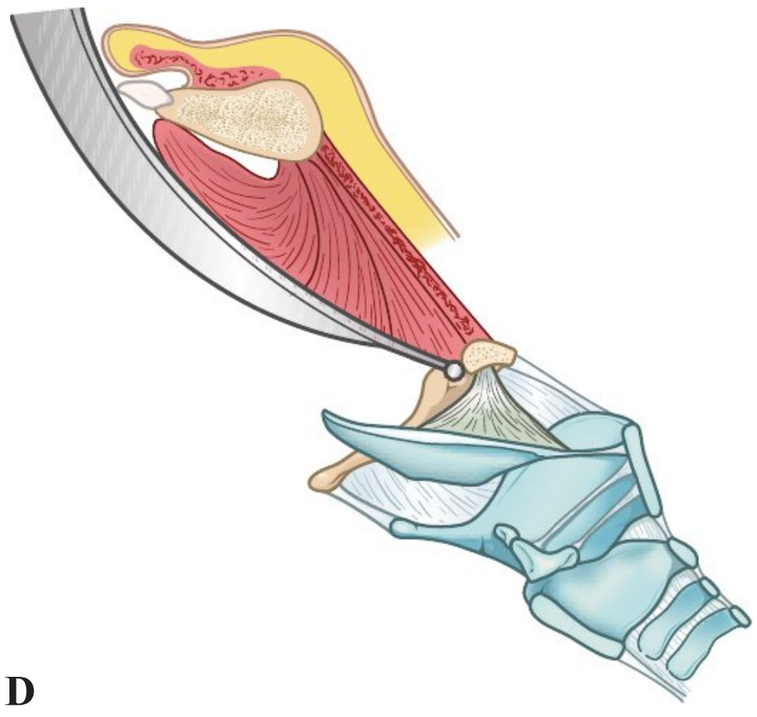
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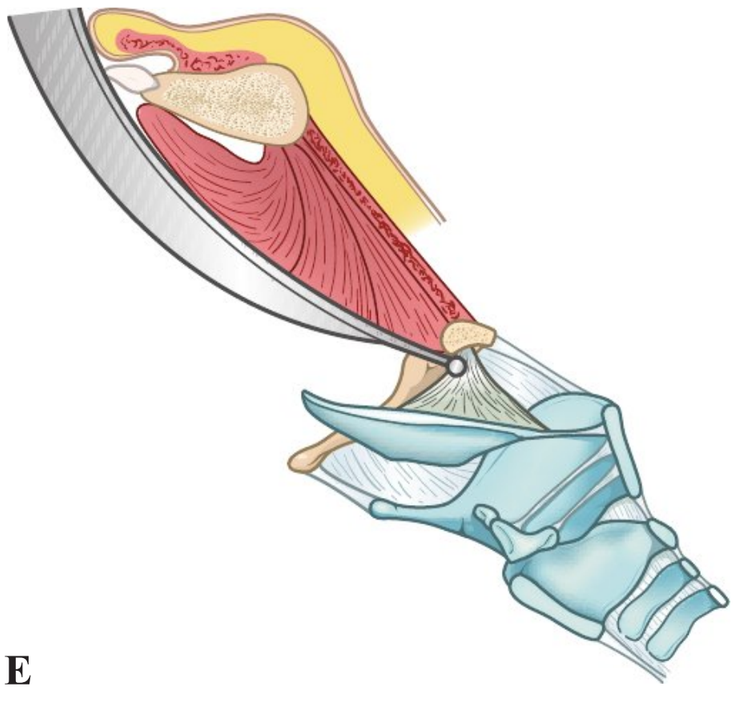
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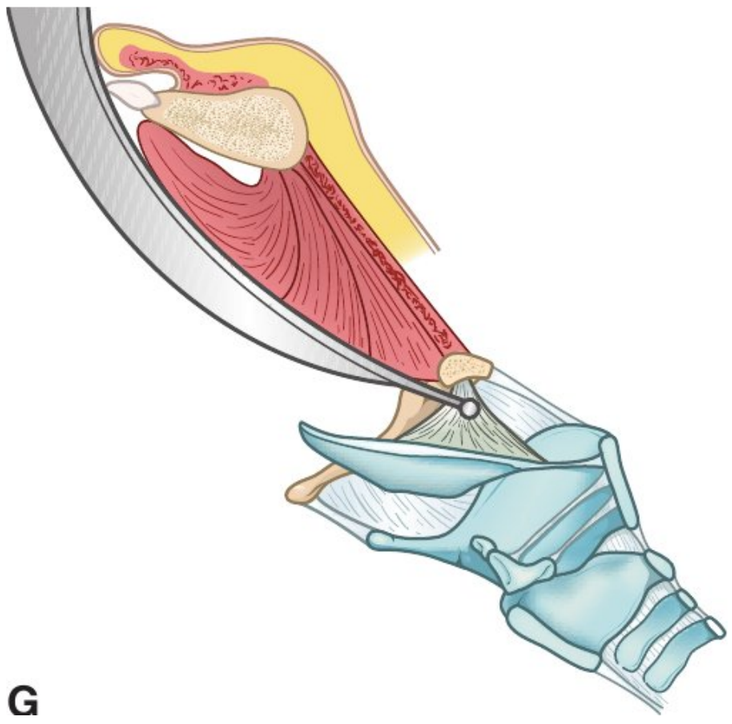
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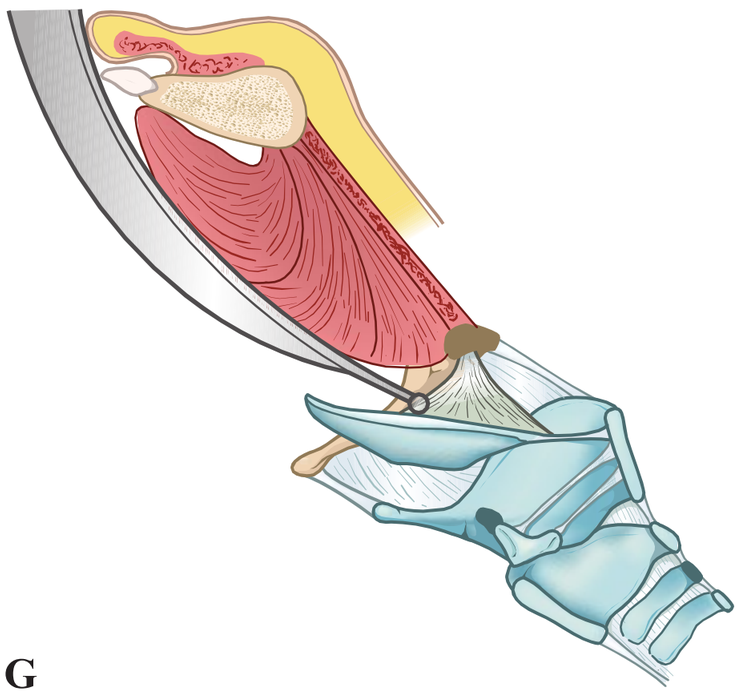


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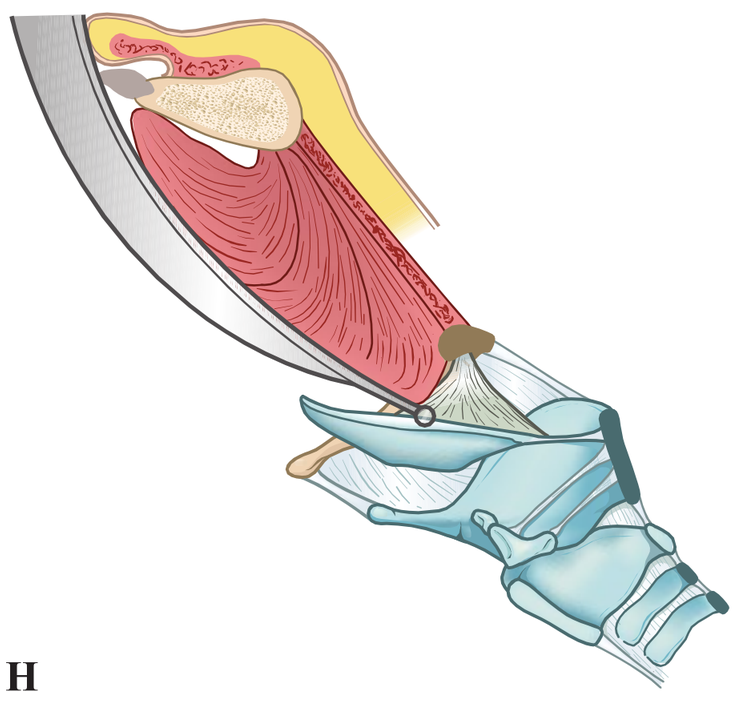


G

FIGURE 1-10 Relationship of the blade tip to the median fold of the HEL. **A:** HEL curvature at rest and **B:** pressed at midpoint to leverage elevation of epiglottis above LOS. Suboptimal epiglottis lift due to positioning in various locations can appear similar on DL (eg, Fig. 1-8). Familiarity with these suboptimal locations can guide repositioning trials. **C:** Shallow placement. When a blade-based view is available, mucosal irregularity of the tongue may be apparent, as in Fig. 1-8B. **D:** Blade tip abutting rather than dorsal to hyoid: although the optimal site is only millimeters deeper, abutment prevents sliding the tip dorsal to the hyoid and against the HEL. **E:** Blade tip is below the hyoid at the base of the HEL; lifting still causes only a sluggish elevation. If the tip is midline, optimal position might result from advance of the blade tip or external pressure on the thyroid cartilage. **F:** If the tip is not midline, advancing the tip into the valecula on either side of the median fold of the HEL still provides less than full elevation. **G:** Placement only millimeters past the optimal point (that is, closer to the epiglottis tip) can prevent elevation, or push the epiglottis caudad, or flex it back on itself. Lifting the blade tip slightly may flip the epiglottis up. **H:** The blade tip is positioned as in **G**, but lift is prevented by the flaccid tongue slurred dorsally between the blade and the hyoid (Peardrop phenomenon, Fig. 1-5).



G



H

FIGURE 1-10 (Continued)

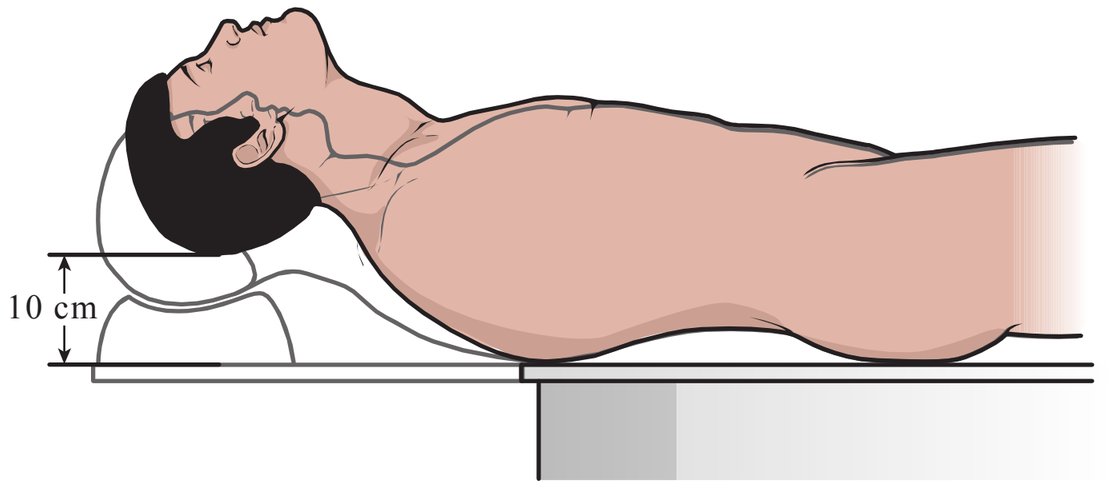


FIGURE 1-11 Head-elevated position for DL, by Chevalier Jackson (1934). For introduction of the laryngoscope, Jackson recommended "The patient's vertex should be 10 cm. higher than the level of the top of the table." Jackson referred to the position now called "sniffing" as "normal recumbency."[21]

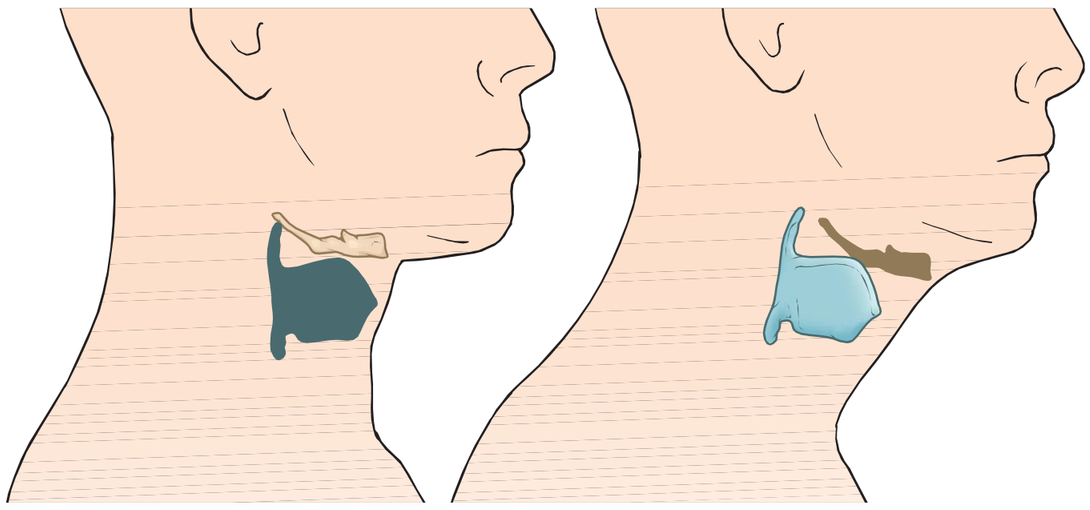


FIGURE 1-12 Palpable demonstration of fore and aft movement of the hyoid relative to the thyroid cartilage. The thyroid cartilage is the most prominent structure and is notched at the top in the midline. The hyoid is the first firm mass below the mandible, at the junction of the neck and chin. It is wider than the thyroid cartilage and can be felt just above the sides of that prominence. Fore and aft movement of the head causes readily palpable antero-posterior movement of the hyoid relative to the thyroid cartilage.

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CHAPTER 2

Mask Ventilation

Mark Backeris and Patricia Dalby

Concept

Mask ventilation is an effective, noninvasive means of providing ventilation and oxygenation in the decompensated or unconscious patient. Maintenance of a patent airway with mask ventilation is an important skill that requires understanding and experience to perform well. Furthermore, the ability to ventilate by mask is life-supporting or even life-saving when direct laryngoscopy proves difficult. In some scenarios, ventilation by mask may be all the airway management necessary to ensure temporary oxygenation and ventilation, while a reversible condition is addressed, and the patient is expected to then resume spontaneous ventilation. When endotracheal intubation is necessary in the elective, fasted setting, as in the operating room, initial ventilation with the face mask should precede attempts at intubation in the apneic patient.

In emergent airway management scenarios, face mask ventilation is often withheld after unconsciousness is induced, in order to avert gastric insufflation and the potential for regurgitation ("rapid sequence induction" or "rapid sequence intubation"). However, the decision to withhold mask ventilation after the delivery of drugs for an emergent intubation is somewhat controversial.[1] In a conscious patient who is dyspneic and hypoxemic, assistance of ventilation with positive pressure or simply high-flow oxygen is appropriate to obtain adequate preoxygenation in preparation for intubation. In an unconscious patient with a reduced oxygen saturation, a period of low-pressure mask ventilation is necessary to avert severe hypoxemia during attempted laryngoscopy, and it should continue after the delivery of the hypnotic and relaxant if high oxygen saturations cannot be restored. Such attempts should be conducted in association with cricoid pressure to reduce gastric insufflation.[2] An assortment of face masks for ventilation is shown in Fig. 2-1. Clear masks are preferred to other types, so that regurgitation or vomitus is immediately apparent.

Evidence

Effective mask ventilation requires an open airway and a tight seal between the mask and the face. Patency of the airway can be optimized with a "triple airway maneuver" in which chin lift, head extension, and mouth opening are provided. Placement of the patient in "sniffing position," with the cervical spine flexed and the head extended, also contributes to this. Mask fit can be optimized with the choice of mask shape and with appropriate inflation of the air-filled bladder, or cushion, which surrounds most modern ventilation masks. As the mask is placed over the mouth and nose, it is imperative that pressure is applied from above as the jaw is lifted into the mask. This is most effectively performed by using the thumb and forefinger of the left hand to apply the mask, while the remaining fingers pull the boney mandible upward. This chin lift-jaw thrust maneuver prevents the soft tissue obstruction of the airway that will occur if the mandible is displaced in a posterior direction with mask pressure in the unconscious patient, or if the fingers apply pressure to the floor of the mouth, obstructing the oral cavity.[3] It is particularly useful to "hook" the fifth finger behind the angle of the mandible to aid in lifting it upward. When attempting to open the airway for bag-mask ventilation, it is important to avoid firm occlusion of the teeth by cephalad pressure with the fingers on the body of the mandible, because it will be impossible to thrust the jaw forward. When making a seal proves difficult, a two-hand technique is preferred. This may utilize the thumb-forefinger technique on the mask, as described above, or the thenar eminences and thumbs may be used for downward pressure, while the other eight fingers are placed on the jaw and behind the angle of the mandible to provide jaw thrust and chin lift.

Mask ventilation also necessitates a source of pressure to move gas into the airway. Depending upon the setting, the oxygen source in bag-mask ventilation may be a hospital wall source, oxygen tank with regulator, or an anesthesia machine and circuit. Effective ventilation is confirmed by visible chest rise and audible breath sounds, as well as the presence of exhaled CO_2, if monitored (as is typical in the operating room). In addition, the "feel" of the ventilation bag may provide clues to a patent airway—when little or no resistance is met to attempts at ventilation, a leak is likely. When compliance is very poor and high pressures (more than 25 to 30 cm H_2O) are required, there is likely to be an upper airway obstruction. Additional causes of high ventilation pressures that should be considered are gastric insufflation, pneumothorax, "stacking" of breaths due to insufficient time for exhalation, and poor lung or

chest wall compliance. High inflation pressures may contribute to gastric insufflation and regurgitation and should be avoided if possible.

Airway obstruction in the unconscious individual is usually attributed to relaxation of the tongue, with posterior displacement of its muscular mass, occluding the airway at oropharyngeal levels. Studies with magnetic resonance imaging in sedated adults suggest that the soft palate plays a very important, and perhaps predominant, role in this phenomenon.[4] Doubtless, both mechanisms may contribute, and overcoming this obstruction is paramount in ensuring oxygenation and ventilation. Either oropharyngeal or nasopharyngeal airways should be used to complement mask ventilation when obstruction occurs, and if ineffective, both may be used together (Figs. 2-2–2-7). Both of these aids must be sized appropriately, or else they may become ineffective or even make obstruction worse.

Various definitions of difficult mask ventilation (DMV) have arisen in the literature, but most include the need to resort to two provider assisted mask ventilation along with the clinical signs of oxygen desaturation and inadequate CO_2 exchange, in the setting of poor chest excursion. At times, mask ventilation may remain difficult or impossible despite optimal technique (Figs. 2-8 and 2-9), even with the use of nasal and/or oral airways. Several predictors exist for evaluating the possibility of encountering DMV, including the presence of a beard, obesity, the lack of teeth, and a Mallampati score of either III or IV.[5] Additionally, it has been shown that operator experience is an important factor in avoiding DMV. An independent study has shown that, on average, it takes approximately 25 mask ventilation procedures to attain an 80% success rate.[6]

DMV may occur in up to 1.4% of cases, but impossible mask ventilation is much less common.[5,7] Under these circumstances, assistance should be obtained and a two-handed, two-person mask technique utilizing the methods mentioned above must be employed (Fig. 2-10). If only unskilled assistance is available (ie, no experience in airway management), then the provider in charge of the airway should use both hands to secure the mask seal, while his/her assistant squeezes the anesthesia bag or resuscitation bag (Fig. 2-11). An intraoral appliance that aids in the maintenance of pharyngeal patency by mandibular advancement called the EMA-T has also been described (Fig. 2-12).[8]

In the case of an edentulous patient, it becomes difficult to maintain an adequate seal because of the absence of tooth structure for soft tissue to rest upon, creating numerous air leaks. Effective mask ventilation may be better achieved by using a "lower lip" facemask placement. This is performed by placing the lower mask edge above the lower lip while maintaining head flexion (Fig. 2-13). When used correctly, this method has been shown to reduce air leak in the edentulous patient by 80% to 100%.[9]

Preparation

- Attach bag-mask apparatus to oxygen source
- Assure flow of oxygen
- Select face mask of correct size and attach to bag-mask or anesthesia circuit
- Place patient in optimal position: neck flexion, head extension ("sniffing" position)

Procedure (Figs. 2-2 to 2-12)

- Open the airway with "triple airway maneuver": head extension, mouth opening, chin lift (in some patients, this may be all that is required to resume ventilation).
- Place the mask on the patients face, using the thumb and forefinger of the left hand on the mask, and the remaining three fingers on the boney mandible, elevating it into the mask; the small finger should be hooked around the angle of the mandible to provide jaw thrust. It can be difficult to obtain an adequate jaw thrust while the mouth is closed and the teeth are touching. For this reason, some mouth opening or the use of an oral airway is advised.
- Squeeze the bag with the right hand, until chest rise is evident
- Ensure optimal seal of the mask on the face: leakage of gas should not occur with inflation pressures up to 25 cm H_2O
- If seal is inadequate, reposition mask or change to a different size mask
- If seal is intact, but ventilation is ineffective, suspect airway obstruction and ensure optimal positioning, mouth opening, and jaw thrust. If not effective, then place oropharyngeal or nasopharyngeal airway
- Confirm adequate ventilation with chest rise, humidification in mask, symmetric breath sounds on auscultation, and presence of expired CO_2 (if capnometry is available)

Practicality

- Simple, inexpensive, portable airway support maneuver
- Requires considerable practice and experience to perform well

Indications

- Altered mental status with inadequate or obstructed ventilation
- Unconscious patient with apnea or inadequate ventilation
- Cardiac arrest
- Pre oxygenation before intubation attempts
- Ventilation after induction of anesthesia in elective surgical cases, preceding placement of endotracheal tube or laryngeal mask airway
- Administration of anesthesia gases throughout certain surgical cases



FIGURE 2-1 Examples of face masks for bag-mask ventilation.

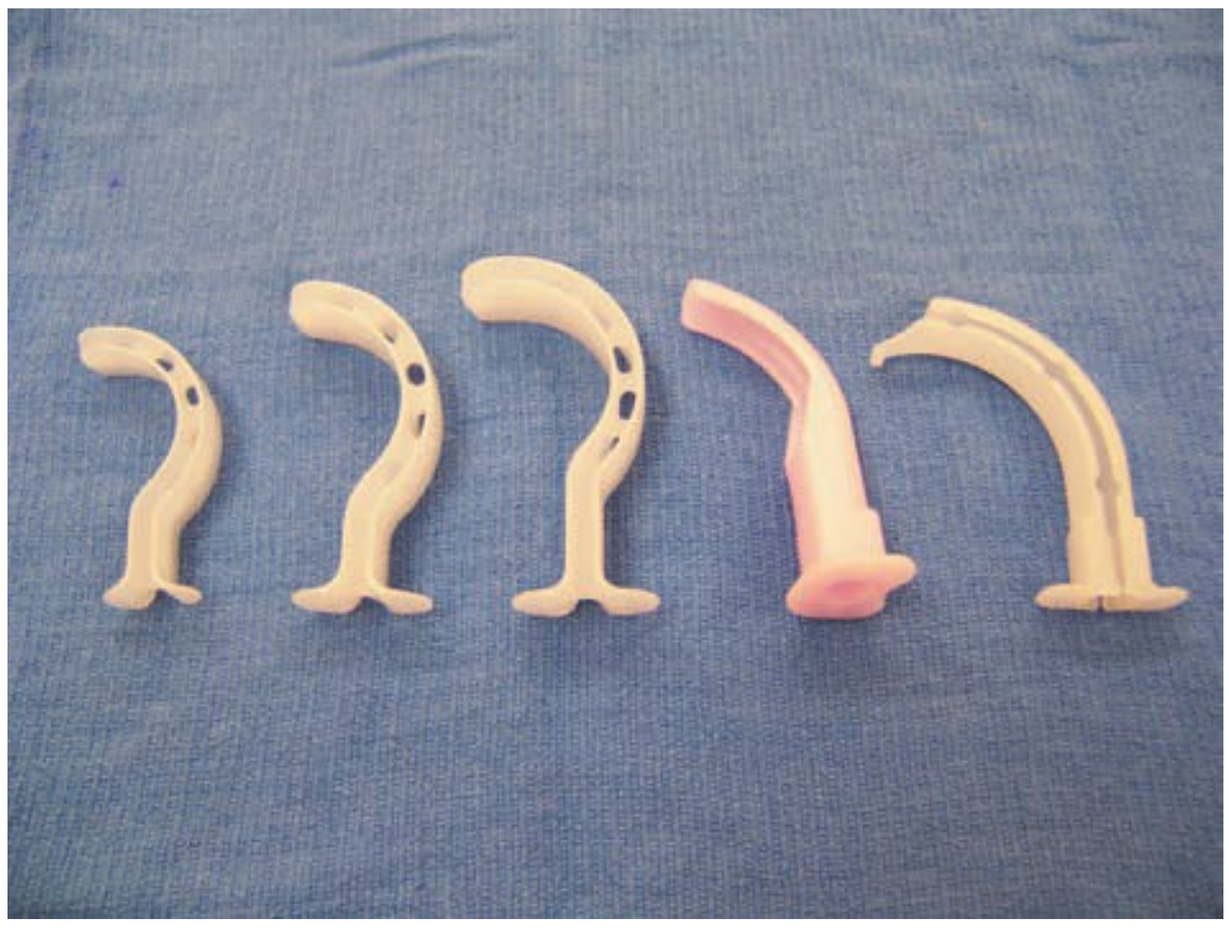


FIGURE 2-2 An array of oropharyngeal airways to assist with bag-mask ventilation.



FIGURE 2-3 An array of nasopharyngeal airways to assist with bag-mask ventilation.

FIGURE 2-4 Proper placement of an oropharyngeal airway, showing effective separation of dorsal tongue from posterior oropharyngeal wall.

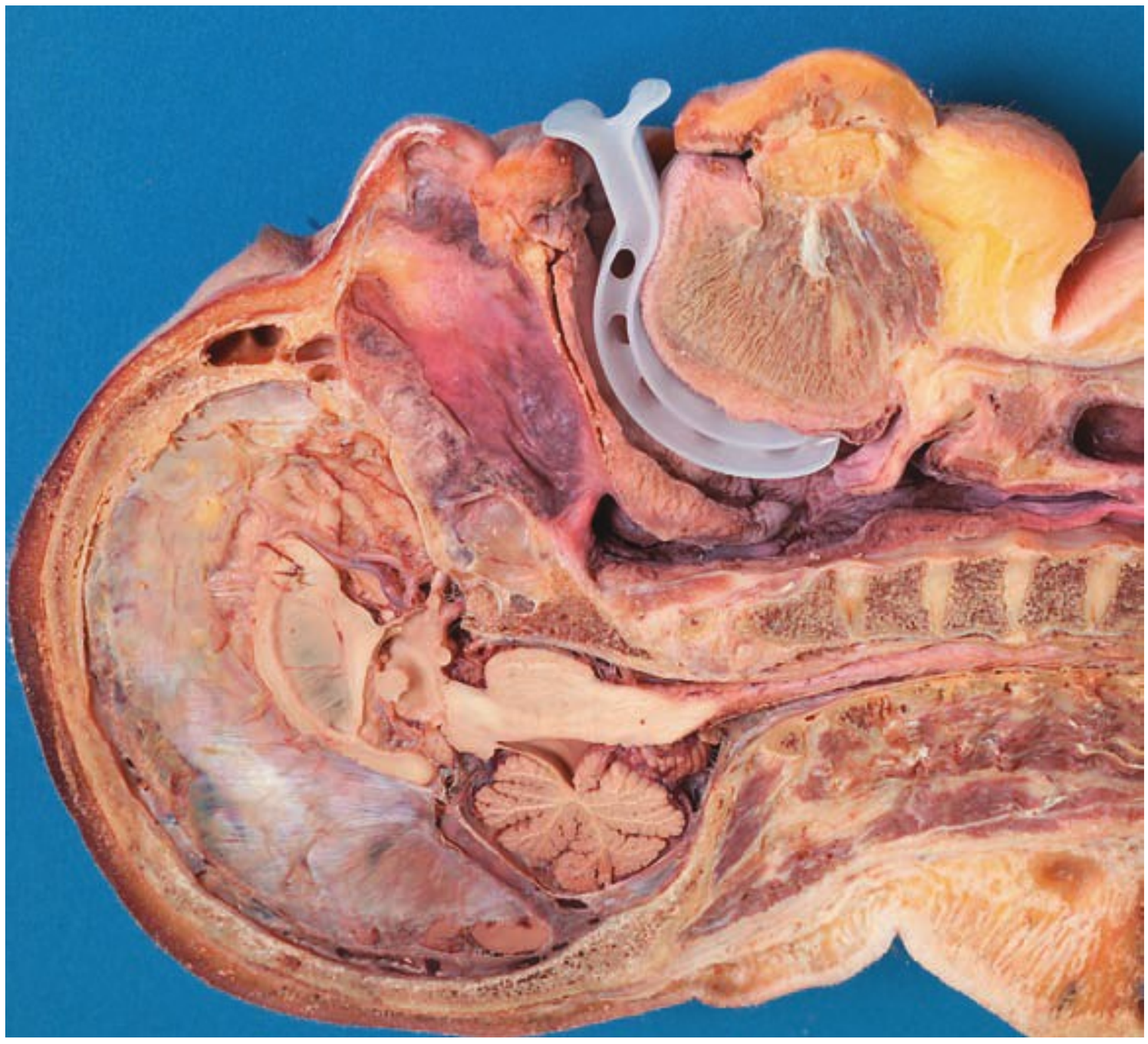
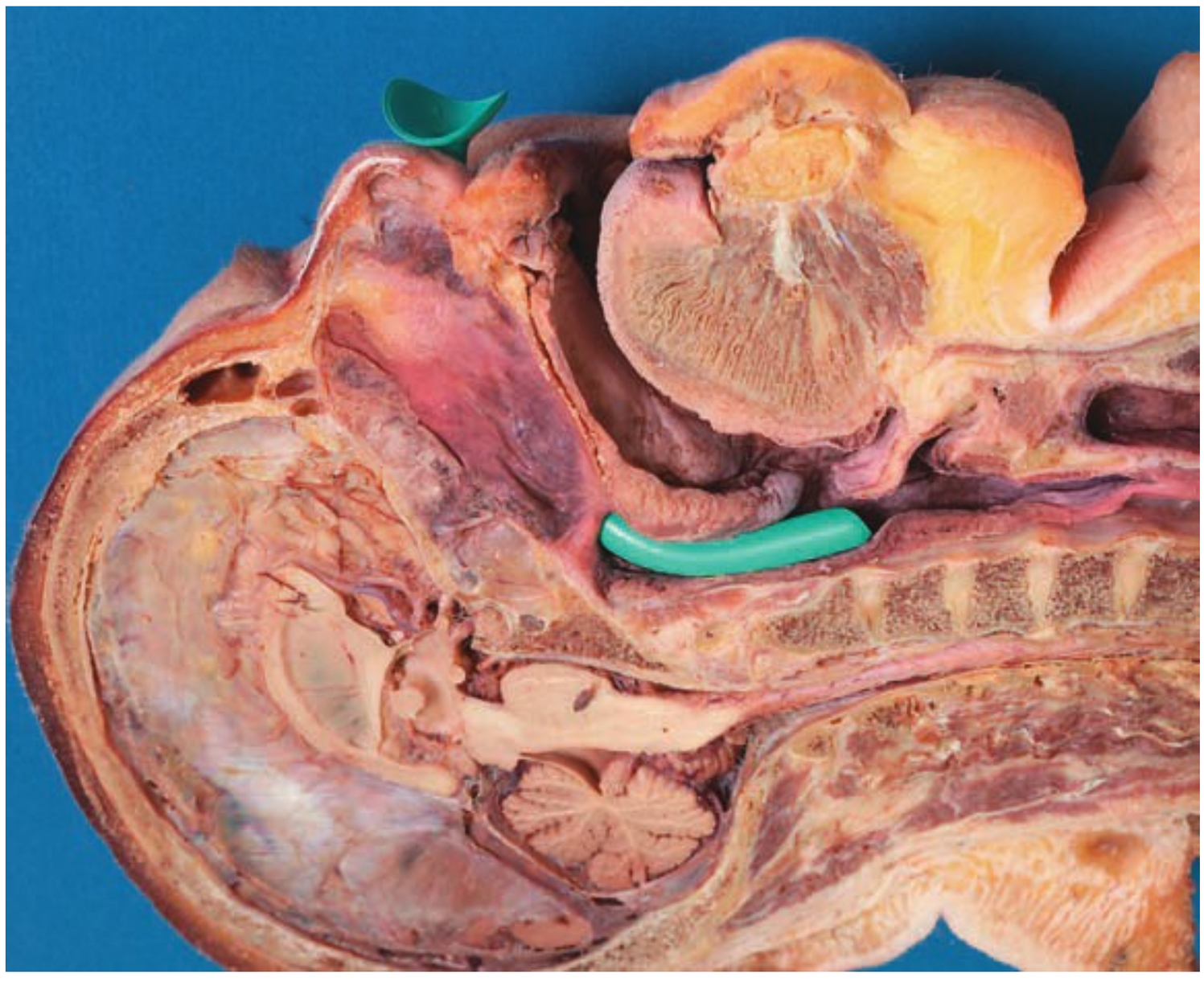


FIGURE 2-5 Proper placement of a nasopharyngeal airway, showing effective separation of soft palate from posterior wall of nasopharynx.



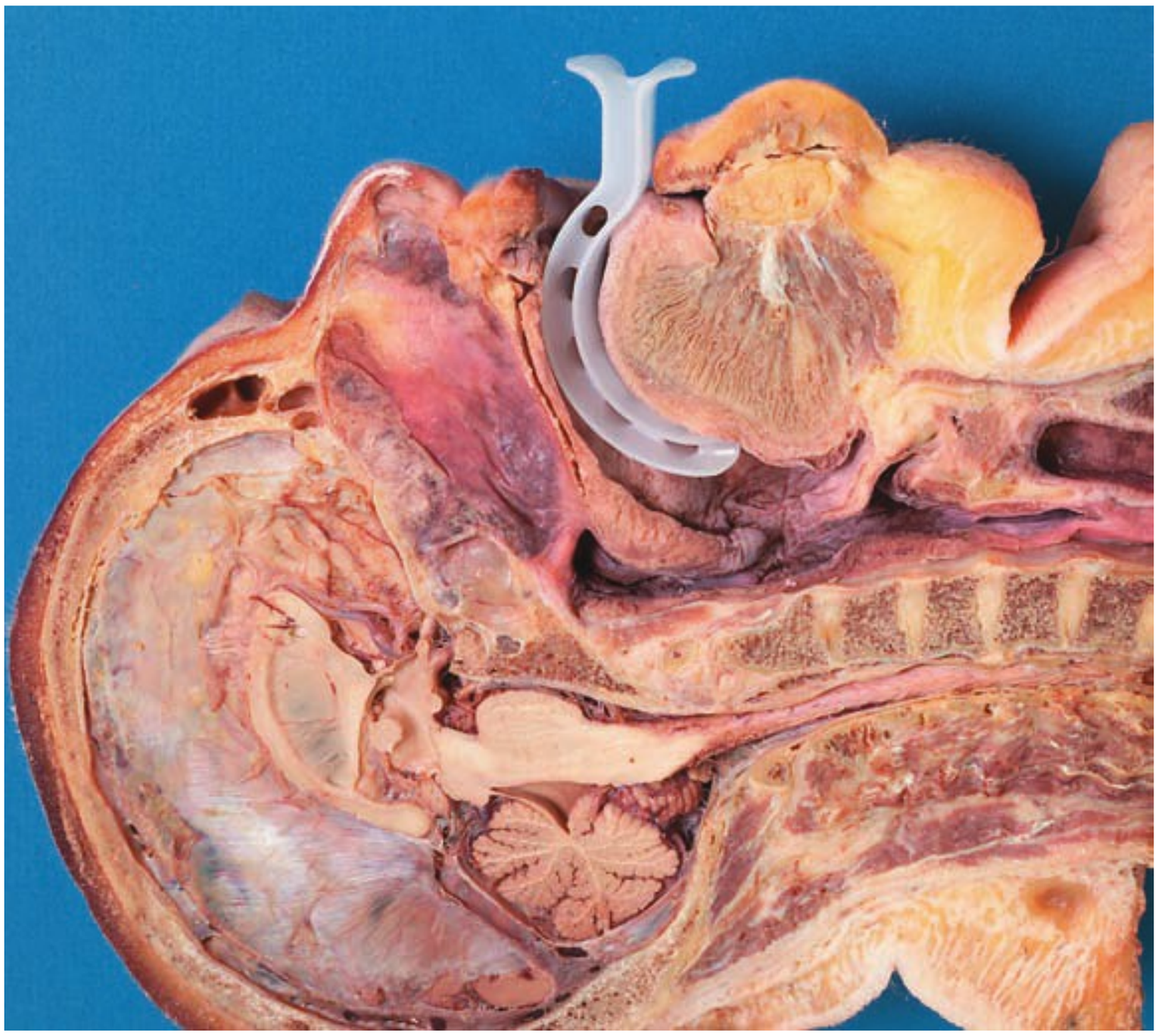


FIGURE 2-6 Improper size and placement of oropharyngeal airway, showing potential increase in obstruction from tongue displacement.

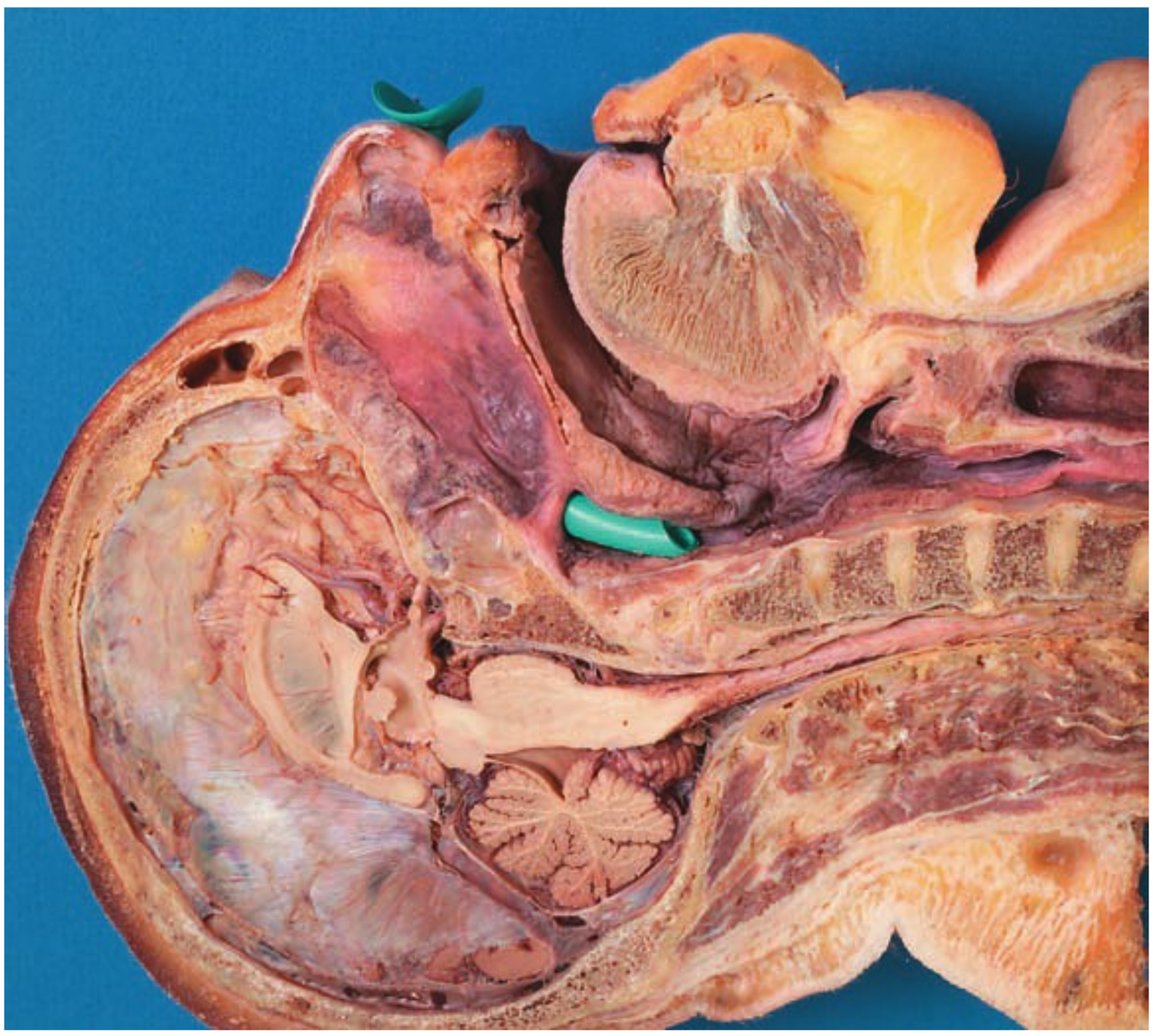


FIGURE 2-7 Improper size of nasopharyngeal airway, showing failed separation of soft palate from nasopharyngeal wall.



FIGURE 2-8 Effective application of the face mask in the unconscious patient, with thumb and forefinger holding mask to face, while the other three fingers pull the mandible up into the mask, creating seal and enacting a chin lift-jaw thrust maneuver simultaneously.



FIGURE 2-9 Detail of application of face mask, showing fifth finger "hooked" behind the mandibular angle, pulling mandible upward into mask with effective jaw thrust. Some mouth opening may facilitate jaw thrust.



FIGURE 2-10 Effective two-person mask technique allows the most skilled provider to perform a two-handed mask seal with jaw thrust, while the second operator uses one hand to enhance mask seal and the other to squeeze the bag. This technique should be employed with oral and/or nasal airways in place to optimize ventilation attempts.



FIGURE 2-11 When only one skilled provider is available, he/she should place both hands on the mask, providing an effective seal, while the unskilled assistant squeezes the bag.



FIGURE 2-12 EMA-T device used for mandibular advancement.

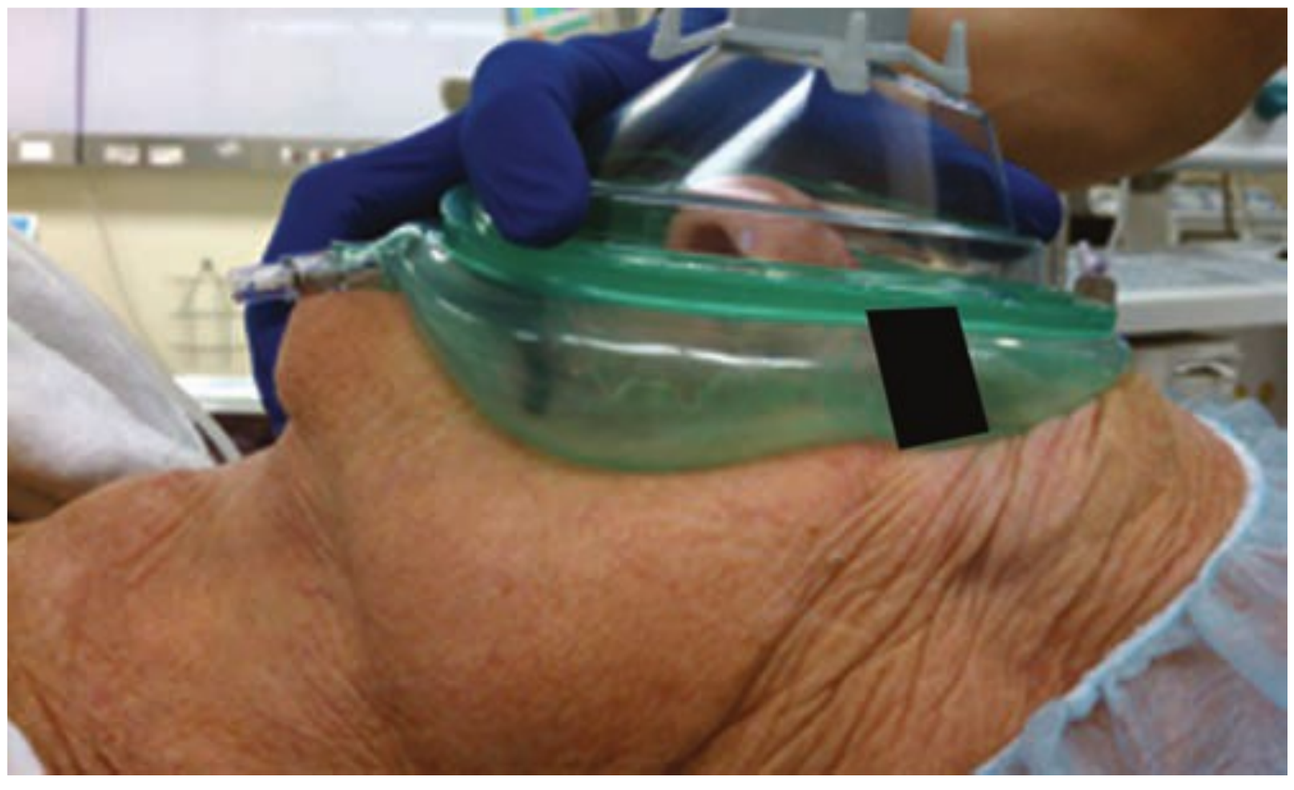


FIGURE 2-13 Using a "lower lip" facemask placement on an edentulous patient performed by placing the lower mask edge above the lower lip while maintaining head flexion.

Contraindications

- Full stomach or risk for regurgitation (however, if hypoxemia occurs, the theoretical risk of aspiration is outweighed by the real occurrence of tissue injury from hypoxia: mask ventilation should be carried out with cricoid pressure)
- Potential cervical spine injury (avoid cervical flexion or head extension: manual, in-line immobilization should be applied before attempts at direct laryngoscopy)
- Severe facial trauma, precluding mask placement or seal
- Upper airway foreign body obstruction: attempts should be made to clear the airway first with appropriate abdominal or chest thrusts

Complications

- Ineffective ventilation with hypoxia and/or hypercarbia
- Gastric insufflation
- Regurgitation/aspiration of gastric contents
- Trauma or bleeding from oral or nasal airways
- Laryngospasm, bronchospasm, or vomiting due to stimulation from oral or nasal airways (especially if placed too deeply)

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CHAPTER 3

Noninvasive Ventilation

Stephen M. McHugh and Mario Montoya

Concept

Noninvasive positive pressure ventilation (NIPPV) is the administration of ventilatory support without the use of an invasive artificial airway such as an endotracheal tube, tracheostomy tube, or laryngeal mask airway. Its use has been rapidly growing since its introduction in the late 1980s and early 1990s[1,2] and it is now utilized as an adjunct to existing medical therapies or even as an alternative to endotracheal intubation for selected conditions. The main advantages of NIPPV are the ability to provide ventilatory support to a patient without the need for sedation and without bypassing airway defenses, both of which are necessary with invasive ventilation. Perhaps the most familiar use of NIPPV is for patients suffering from obstructive sleep apnea for which it is considered the standard of care[3] and is provided by portable home devices (Fig. 3-1). However, in other groups of patients, most notably those suffering from exacerbations of chronic obstructive pulmonary disease (COPD) and cardiogenic pulmonary edema, NIPPV has been shown to decrease intubation rates and in-hospital mortality.[4,5] As experience with NIPPV grows, it is being evaluated in a growing number of scenarios, including postextubation respiratory failure (Fig. 3-2), as a component of ventilator weaning in the ICU and as a method to provide ventilatory support to patients with do-not-intubate status.[6–8] Although the range of conditions responsive to NIPPV is expanding, patient selection is still key to its successful implementation.

Evidence

Successful use of NIPPV requires correct selection of both patient and equipment. Although the two acute conditions most likely to respond to NIPPV are exacerbations of COPD and congestive heart failure, patients must be evaluated on an individual basis for suitability for NIPPV.



FIGURE 3-1 An example of a bilevel positive pressure ventilation device with an integrated humidifier. Newer devices are much smaller in size than older models.
(©ResMed 2010. Used with permission.)

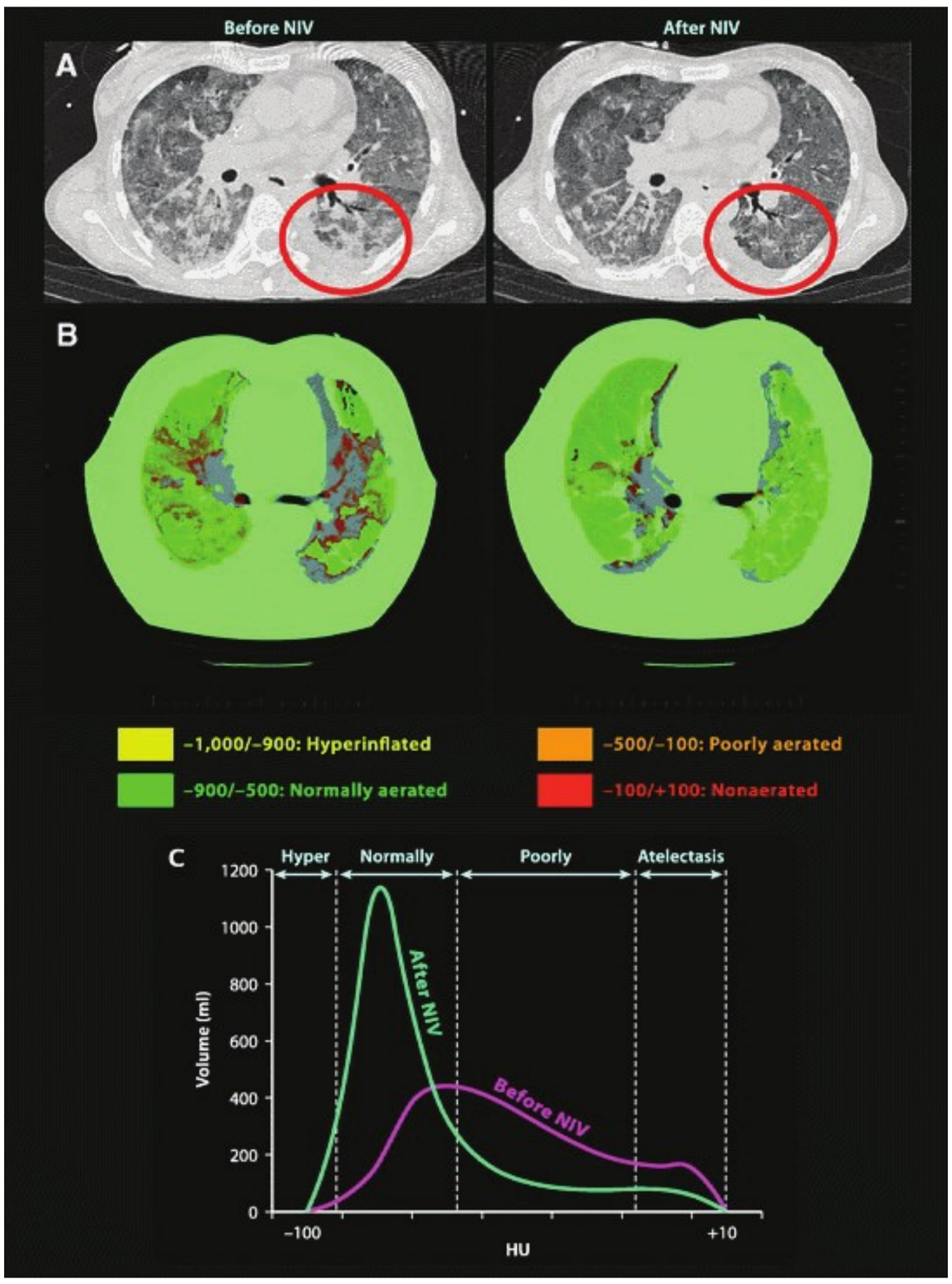


FIGURE 3-2 This image shows the effects of 30 minutes of NIPPV on computer tomography lung volumes in a patient with acute respiratory failure after abdominal surgery. Note the decrease in poorly aerated lung regions following NIPPV.

(From Jaber S, Chanques G, Jung B. Postoperative noninvasive ventilation. *Anesthesiology*. 2010;112:453–461 with permission.)

Tables 3-1 and 3-2 list criteria to consider when evaluating a patient for NIPPV.

NIPPV can be provided via a variety of different interfaces. The characteristic that they all share is the ability to provide positive pressure. Oronasal masks were among the earliest interfaces and are still the most commonly used (Figs. 3-3 and 3-4).[9] These masks cover both the nose and the mouth. They may be particularly effective for an acutely dyspneic patient as these patients tend to breathe through their mouths rather than their noses.[10] However, these masks increase the risk of aspiration in a vomiting patient because they interfere with the expectoration of gastric contents. Quick-release mechanisms on newer oronasal masks decrease this risk but require the patient to be awake and alert in order to release their mask. Nasal masks decrease the aspiration risk and allow the patient to speak while receiving NIPPV, but they increase the risk of air leaks through the mouth (Figs. 3-5 and 3-6). Mouthpieces, nasal pillows (Fig. 3-7), total face masks, and helmets may also be used to provide NIPPV. Each interface has its own set of advantages and disadvantages (Table 3-3).

Once an interface is chosen, the proper fit must be obtained. First, the correct size is determined using sizing guides provided by the manufacturer. For the most commonly used oronasal mask, the patient is instructed to slightly open their mouth and the smallest mask that contacts the bridge of the nose, the area just lateral to the corners of the mouth, and the area just below the lower lip is chosen (Fig. 3-8).[10] Selecting a mask larger or smaller than this may result in patient discomfort and air leaks. Next, the mask must be secured to the patient using the attached head straps. The head straps on today's oronasal masks are adjustable in multiple areas and the manufacturer's instructions will provide detailed information on obtaining the optimal fit for each model. However, for all NIPPV interfaces, the general rule applies that the head straps must be applied securely enough to prevent dislodgement with patient movement while avoiding the side effects of over-tightening. Applying the mask too tightly will increase patient discomfort and potentially lead to skin irritation and even necrosis and ulceration. In general, the practitioner should be able to slip one finger between the strap and the patient's head and there should be no skin bulging or erythema evident around the edges of the mask (Fig. 3-9). This will limit complications due to excessive pressure while still keeping air

Table 3-1

Clinical Indications for NIPPV

1. Moderate to severe dyspnea
2. Tachypnea (>24 breaths/minute)
3. Increased work of breathing (accessory muscle use, paradoxical abdominal motion)
4. Hypercapnia ($PaCO_2$ > 45mmHg, pH < 7.35)
5. Hypoxemia (PaO_2/FiO_2 < 200)

Adapted from Soo Hoo GW. Ventilation, noninvasive. 2010. *http://emedicine.medscape.com/article/*304235.

Table 3-2

Selection Criteria for NIPPV

1. Patient is conscious and cooperative
2. Patient can protect airway
3. Patient is hemodynamically stable
4. No active gastrointestinal bleeding
5. No impairment in swallowing
6. No facial deformities impairing fit of the interface

Adapted from Antonelli M, Pennisi MA, Montini L. Clinical review: noninvasive ventilation in the clinical setting—experience from the past 10 years. *Crit Care*. 2005; 9(1):98–103.



FIGURE 3-3 Example of an oronasal mask. Masks are available in a variety of different sizes and models. (©ResMed 2010. Used with permission.)



FIGURE 3-4 A patient wearing an oronasal mask.



FIGURE 3-5 Example of a nasal mask. (©ResMed 2010. Used with permission.)



FIGURE 3-6 A patient wearing a nasal mask. Note that the mouth is uncovered, allowing the patient to speak, eat, and expectorate secretions but also increasing the risk of air leaks through the mouth.

FIGURE 3-7 A patient demonstrating nasal pillows. This type of interface allows access to the skin of the face and does not cover the mouth but can cause pressure sores of the nares if applied too tightly.
(©ResMed 2010. Used with permission.)



Table 3-3

Advantages and Disadvantages of Patient Interfaces Used in NIPPV

Interface	Advantages	Disadvantages
Oronasal mask	Reduces air leakage through mouth	Increased aspiration risk
	Decreased airway resistance	Increased sensation of claustrophobia
		Mask must be removed to expectorate secretions, speak, and eat
Nasal mask	Decreased sensation of claustrophobia	Mouth leaks
	Low risk of aspiration	Higher resistance through nasal passages
	Allows patient to clear secretions, speak, and eat	Eye irritation
Nasal pillows	Increased access to skin of the face	Pressure sores around nares
Mouthpieces	No headgear required	Nasal air leakage
	Low risk of aspiration	Hypersalivation

Adapted from Pilbeam SP, Cairo JM, eds. *Mechanical Ventilation: Physiological and Clinical Applications*. 4th ed. St. Louis, MO: Mosby; 2006.



FIGURE 3-8 A patient wearing an appropriately sized oronasal mask. Note that the mask extends from the bridge of the nose to just below the lower lip and just lateral to each corner of the mouth.

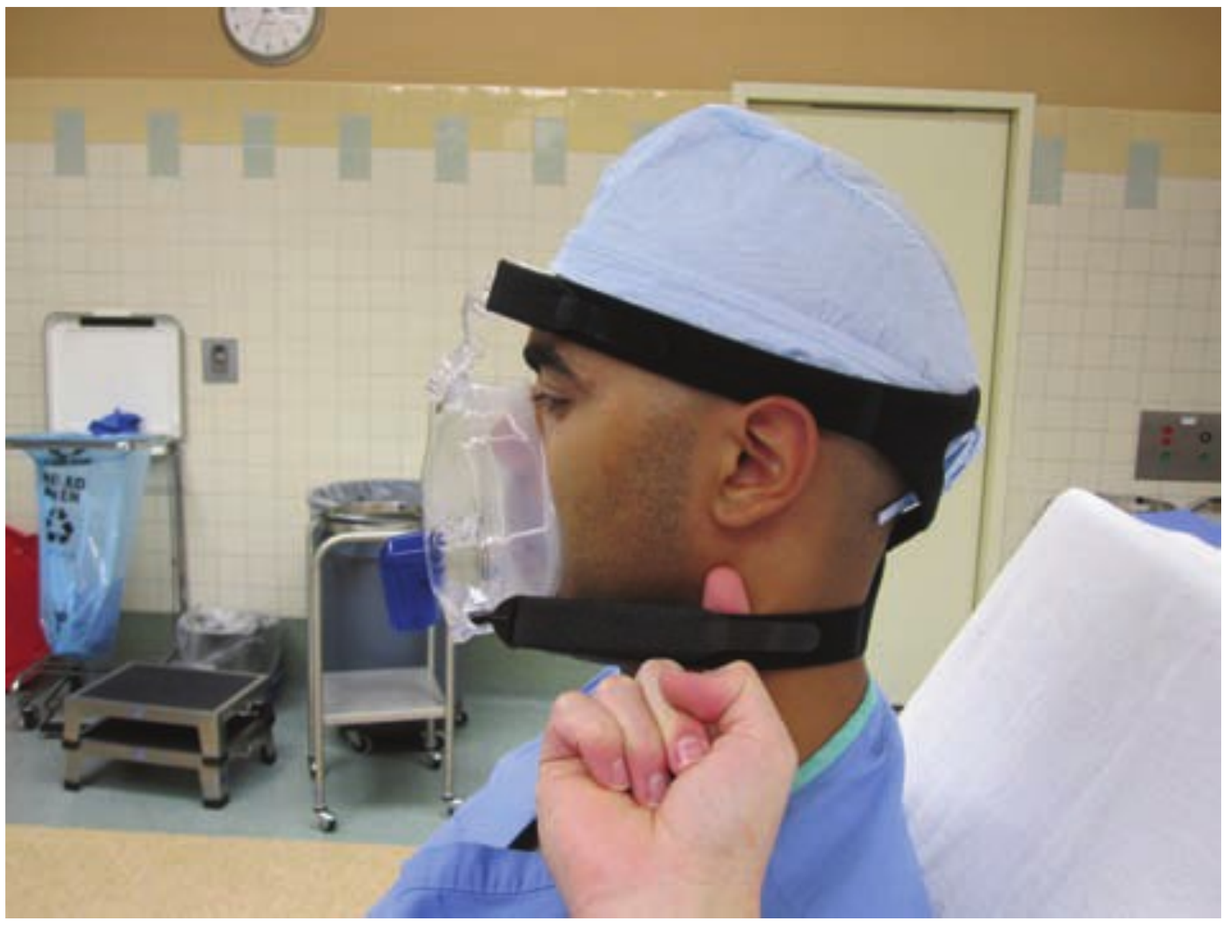


FIGURE 3-9 An oronasal mask with head straps adjusted to the appropriate tension. Note that one finger can be placed between the strap and the patient's skin.

leaks to a minimum. Lack of patient response to NIPPV may be addressed by refitting the interface or choosing a different type of interface; however, establishment of a definitive invasive airway should not be delayed if the patient's condition is deteriorating.

Suggested initial settings for a patient new to NIPPV include an inspiratory positive airway pressure (IPAP) of 10 to 15 cm H_2O, an expiratory positive airway pressure (EPAP) of 3 to 5 cm H_2O, and an FiO_2 level titrated to maintain SpO_2 measurements greater than 95%. If these settings are tolerated, IPAP can then be increased up to a maximum of 20 cm H_2O and EPAP to a maximum of 10 cm H_2O as needed to produce decreased dyspnea, decreased respiratory rate, and increased tidal volumes.[11] Maximum IPAPs should be kept below 25 cm H_2O as pressures below this level should not increase the risk of gastric distention.[2] These initial settings are appropriate for most conditions in which NIPPV has been shown effective. However, in hypoxemic patients, some authors recommend using continuous positive airway pressure (CPAP) at levels of 8 to 10 cm H_2O over bilevel PAP.[12] Additionally, in patients suffering from cardiogenic pulmonary edema, NIPPV settings must be chosen with caution as there is some evidence that CPAP may be superior to bilevel PAP by resulting in a lower rate of myocardial infarction.[13]

Preparation

- Select desired interface and size using sizing guide from manufacturer
- Attach interface to ventilator
- Select desired IPAP, EPAP, and FiO_2; an IPAP of 10 to 15 cm H_2O and EPAP of 3 to 5 cm H_2O with an FiO_2 sufficient to maintain SpO_2 measurements above 95% are often chosen as initial settings[11]
- Assure flow of oxygen

Procedure

- Place patient in an upright or semi-upright position
- Place interface onto patient and confirm sizing
- If the patient is using the interface for the first time, hold it lightly to their face and allow them to breathe through it for a short period before applying head straps
- Tighten head straps so that one finger can be placed between the strap and the patient's head
- Observe the patient while they acclimate to NIPPV and watch for signs of clinical deterioration necessitating discontinuation of NIPPV
- If the seal is inadequate and there is excessive air leakage, re seat the interface by lifting it away from the patient's face and placing it back in the correct position and reevaluate head-strap tension, interface size, and type of interface (small air leaks are to be expected and should be tolerated if not interfering with patient comfort) (Fig. 3-10)
- Adjust IPAP and EPAP levels as needed

Practicality

- May avoid intubation
- Relatively inexpensive
- Easily and quickly initiated and discontinued

Indications

- COPD exacerbation
- Congestive heart failure exacerbation
- Asthma exacerbation
- Postextubation respiratory distress
- "Do-not-intubate" status
- Restrictive thoracic disorders
- Obstructive sleep apnea
- Idiopathic hypoventilation

Contraindications

- Respiratory arrest
- Impaired respiratory drive
- Need for airway protection
- Hemodynamic instability
- Uncooperative patient
- Excessive secretions
- Facial deformity
- Altered mental status impairing cooperation with machine or resulting in impaired airway reflexes

Complications

- Ineffective ventilation
- Aspiration
- Facial skin irritation and necrosis
- Eye irritation
- Gastric insufflation



FIGURE 3-10 **A:** Example of an improperly fitted oronasal mask with malpositioning of the forehead support arm and insufficient tension on the inferior straps resulting in an air leak around the chin and mouth. **B:** Example of an air leak around the nose from excessive inferior strap tension and malpositioning of the forehead support arm.

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CHAPTER 4

Retraction Blades for Direct Laryngoscopy

Dustin J. Jackson and Joseph F. Talarico

The purpose of the laryngoscope is to retract the mandible and soft tissues of the anterior oropharynx upward, allowing visualization of the glottis. In cross section, the blade of the laryngoscope typically consists of a flat portion (spatula) and a vertical portion (flange), along with a light source. These components are arrayed in a large variety of shapes and configurations to meet the challenge of elevating soft tissues during retraction and keeping them out of the line of sight of the laryngoscopist, while at the same time permitting the necessary manipulations to insert an endotracheal tube (ETT). Since the origins of laryngoscopy in the late 19th century, laryngoscopes have undergone an evolution in shape. Early versions had a "C" shape configuration but did not have either detachable blades or an intrinsic light source. By the middle of the 20th century, laryngoscopes incorporated with these innovations had been developed. More modern laryngoscopes contain a light source in the handle with fiberoptic bundles in the blades. The older-style laryngoscopes remain in use by ear-nose-throat (ENT) surgeons today for diagnostic and therapeutic procedures involving the airway.

Many different types of retraction blades for direct laryngoscopy are available today. Although many variations of the straight and curved blade exist, the Miller and Macintosh blades, introduced in the 1940s, remain the most commonly used blades in clinical practice (Figs. 4-1 and 4-2).[1,2] Conventionally, the straight blade is inserted beneath the epiglottis and is used to directly lift it, exposing the glottis (Fig. 4-3). The curved blade, on the other hand, fits into the vallecula, exerting upward traction on the glossoepiglottic ligament as it is lifted, thereby indirectly raising the epiglottis superiorly and allowing the operator to visualize the exposed glottis (Fig. 4-4). The choice of laryngoscope blade is largely based on the personal preference of the operator, with both Macintosh and Miller blades being a reasonable choice for a "normal" airway. In general, the advantages of the Macintosh blade include more room for passage of the ETT, whereas the Miller blade may provide better visualization in patients with a small mandibular space, large incisor teeth, or a large epiglottis (see also Chapter 5).[3]

Some variants of the Miller blade, such as the Phillips (Fig. 4-1) or Wisconsin blade, have a higher vertical profile, answering one of the deficiencies of the Miller blade: inadequate space for ETT manipulation in the pharynx despite an adequate view of the glottis. A variant of the Macintosh blade, the Bizzarri-Giuffrida blade, incorporates the curved design but eliminates the vertical flange, allowing insertion into small mouth openings or in patients with prominent or fragile teeth (Fig. 4-5). The McCoy blade is an articulating blade that allows the user to lift its distal tip in order to improve the view of the glottis if the epiglottis remains downfolded and impedes visibility.[4] This blade has been compared with the standard Macintosh blade, and it produced a better view in almost 60% of patients in whom cords were not seen with the Macintosh blade.[5] When a grade 3 view was obtained with the McCoy blade in the neutral position, elevation of the tip significantly improved visualization; but when a grade 1 or 2 view was obtained with the blade in the neutral position, elevation of the tip worsened the view in 23% of patients.[6] The McCoy levering laryngoscope blade is marketed as the "Flipper" (Rusch, Inc. Research Triangle Park, NC) and also as the "Flex Tip" (Heine USA, Dover, NH).

Other designs include the Choi blade, which is a double-angle blade that combines features of both the straight and curved laryngoscope blades (Fig. 4-6). This may be of benefit in patients with an anterior glottis, a large tongue or "floppy" epiglottis, and also in patients with prominent upper incisors, owing to its lack of vertical flange.[7] The "Improved View Macintosh" blade allows for an enhanced view of the larynx because of a concavity in the flat portion of the blade (Fig. 4-7).[8] A new curved blade has been described by Nishikawa, which has an S-shaped spatula and bifid tip designed to prevent posteroinferior displacement of the compressed tongue, thereby allowing better laryngeal views in patients with a large or prominent tongue (Fig. 4-8).[9] Blades that incorporate mirrors or prisms to aid in direct laryngoscopy also exist, and these will be discussed further in Chapter 16. Table 4-1 details



FIGURE 4-1 Two sizes of Miller laryngoscope blades and Phillips **(bottom left)** blade.



FIGURE 4-2 Two sizes of Macintosh laryngoscope blades.

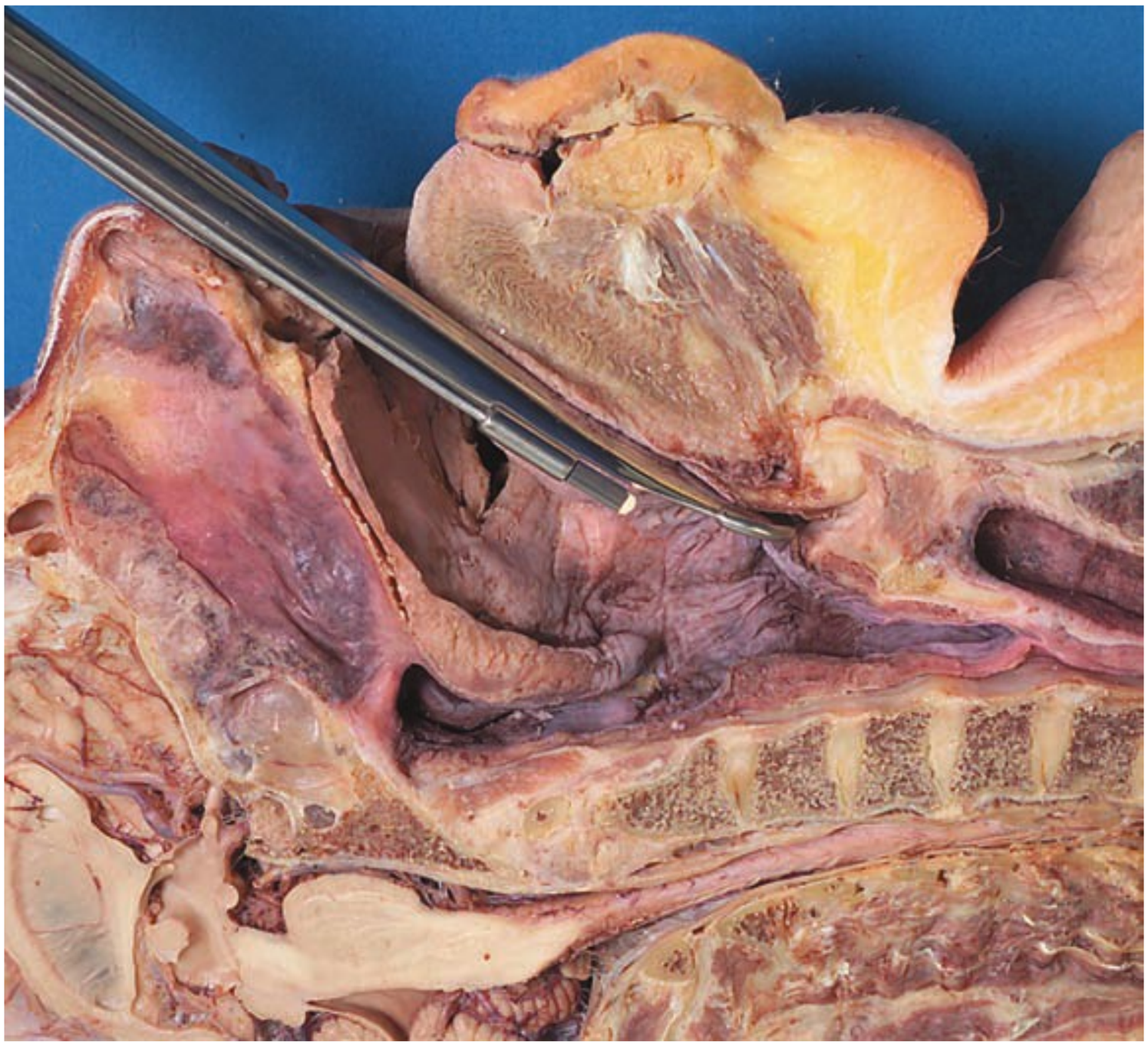


FIGURE 4-3 Miller blade shown directly lifting epiglottis.

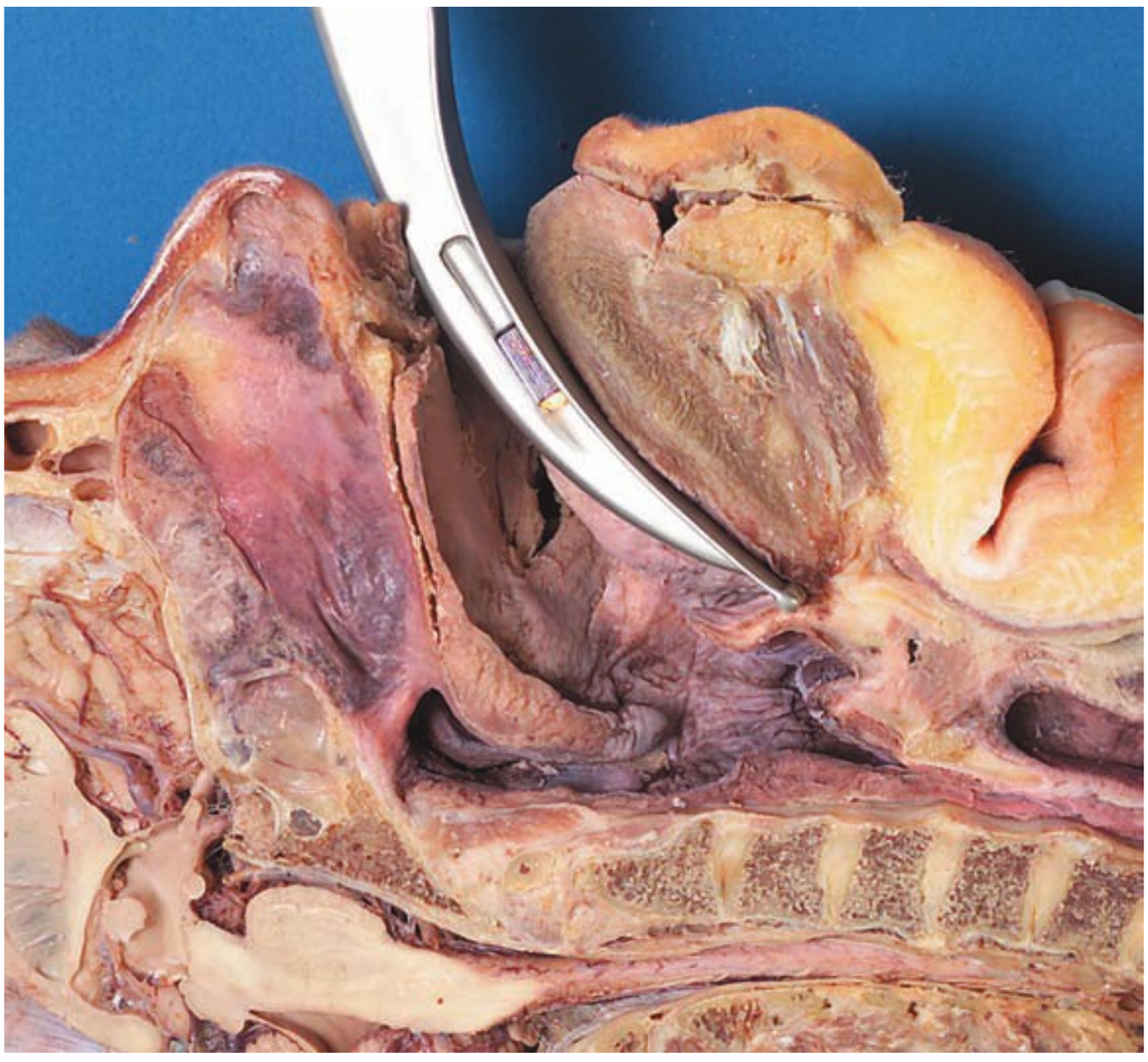


FIGURE 4-4 Macintosh blade shown with tip in vallecula.



FIGURE 4-5 Bizzarri-Giuffrida laryngoscope blade. No vertical flange is present to allow insertion into a small oral cavity or for those patients who cannot open the mouth well.



FIGURE 4-6 Choi laryngoscope blade. No vertical flange and double-angle design, for patients with an anterior glottis, large tongue, floppy epiglottis, or prominent teeth.



FIGURE 4-7 "Improved View" Macintosh laryngoscope blade. This blade contains a concavity in the flat portion or "spoon" of the blade, permitting a better view of the glottis.

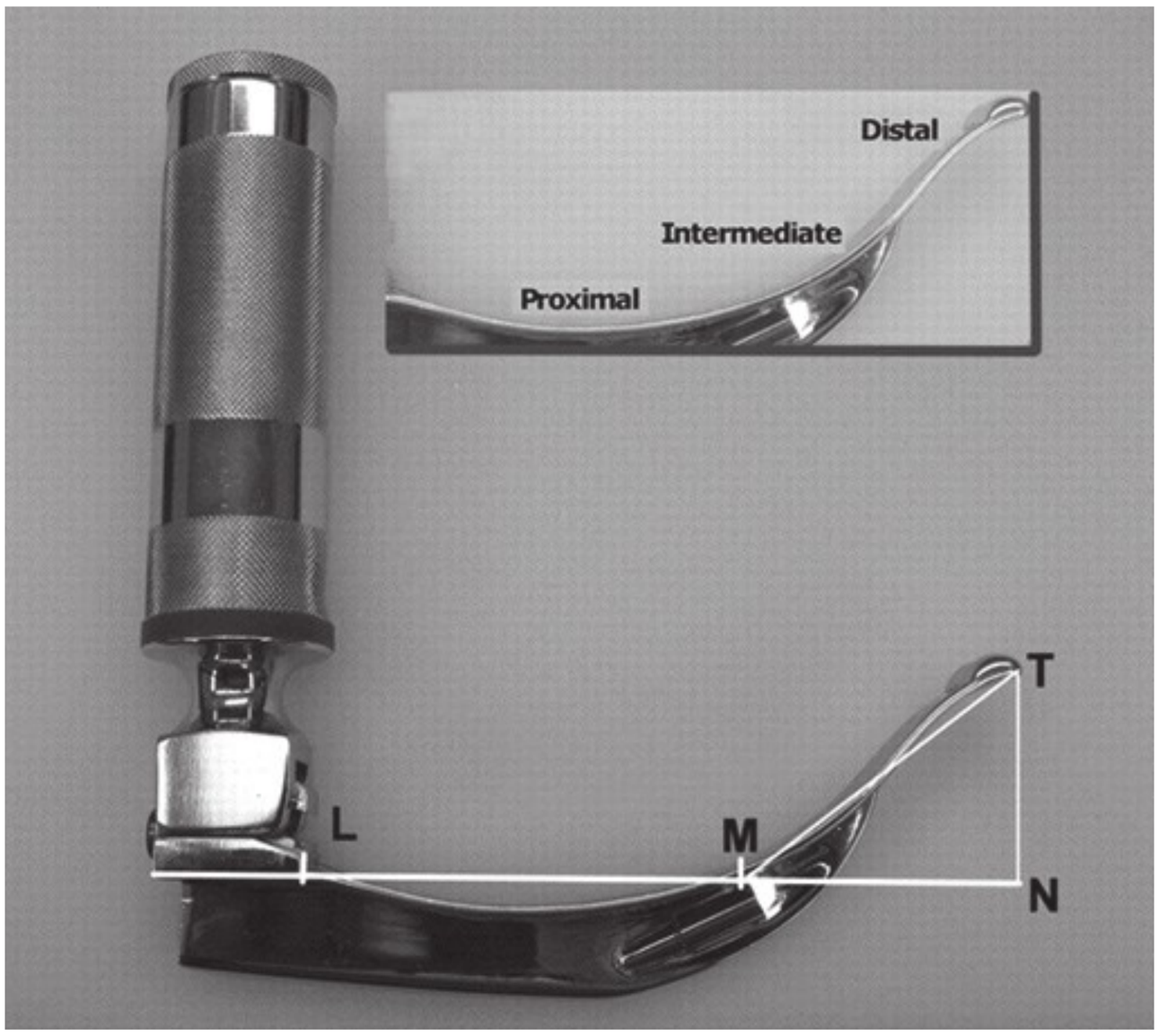


FIGURE 4-8 Nishikawa laryngoscope blade. This blade has an S-shaped spatula and bifid tip, designed to manage the bulk of a large tongue. (From Nishikawa K, Yamada K, Sakamoto A. A new curved laryngoscope blade for routine and difficult tracheal intubation. Anesth Analg. 2008;107:1248–1252 with permission.)

Table 4-1

Selected Retraction Blades

Blade	Characteristics	Uses/Advantages
Straight Blades		
Miller	Straight blade with curved tip	Normal airway, long epiglottis, "deep" glottis, prominent upper incisors
Phillips and Wisconsin	Straight blade with higher vertical profiles than Miller	More room for ETT placement than Miller
Curved Blades		
Macintosh	Curved blade	Normal airway
Bizzarri-Giuffrida	Curved blade with no vertical flange	Small mouth opening or protruding or fragile teeth
McCoy	Curved blade with adjustable, articulating tip	Facilitates lifting of epiglottis
Choi	Double-angle blade	Anterior glottis, large tongue, floppy epiglottis, prominent teeth
Improved-view Macintosh	Concavity in long axis of spatula	Better view of anterior glottis
Nishikawa	Curved S-shaped blade	Prevents posteroinferior displacement of compressed tongue
Siker	Incorporates mirror into blade	Anterior glottis
Belscope	Angulated, optional prism attachment	Anterior glottis or normal airway

characteristics and advantages of the most common blades as well as some less common ones.

Some common laryngoscope blades have been incorporated into video laryngoscope systems (see Chapter 24) and thus lend themselves to conventional direct laryngoscopy, as well as use of the video screen for visualization of the glottis and ETT placement. Such tools are also quite useful for teaching direct laryngoscopy, because the instructor, while viewing the screen, is able to appreciate a direct laryngscopy view quite similar to that of the trainee. The DCI video system (Karl Storz Endoscopy-America, El Segundo, CA) is one such example, with an ergonomically designed handle, which houses the camera, to which is affixed one of several different standard-shape laryngoscopy blades. These include Macintosh size 2-4, Miller size 0-4, and the Dorges "hybrid" blade, which has features of both the Macintosh and the Miller blades.

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CHAPTER 5

Direct Laryngoscopy

James Snyder and Steve Orebaugh

CONCEPT

When face mask ventilation is inadequate to provide necessary airway support, or when long-term positive pressure ventilation is required, an endotracheal tube (ETT) should be placed. In most circumstances, direct laryngoscopy (DL) is the simplest and most readily applied means of placing the ETT. Indications for DL and endotracheal intubation are summarized below (Table 5-1).

Table 5-1

Indications for Tracheal Intubation

Indication	Example
Airway patency	Unconscious patient
Airway protection	Patient at risk for aspiration
Oxygenation failure	Pneumonia with hypoxemia
Ventilation failure	Severe asthma with respiratory failure
Management of secretions	Copious sputum from pneumonitis
Provision of hyperventilation	Increased intracranial pressure
Drug administration	Inability to secure intravenous access
Muscle paralysis for surgery	Intra-abdominal and intrathoracic surgery

When difficulty is unlikely and when conditions are optimized prior to the attempt at intubation (for instance, during elective cases in the operating room), the standard sniffing position is an efficient starting position for experienced practitioners to intubate unassisted.

EVIDENCE

On the other hand, various factors weigh toward optimizing conditions to ensure "first pass success." Preparation for successful intubation on the first attempt is indicated by urgency, anatomic predictors of difficulty (see Chapter 9), cardiopulmonary instability, a likely full stomach, possible gastric insufflation by first responders in codes, overly large body habitus, and (especially) limited operator experience.

KEYS TO "FIRST PASS SUCCESS"

The case for first pass success has been well summarized by Levitan.[1] In emergent or unplanned situations requiring intubation, maneuvers to cope with unpredicted difficulty are planned into the approach rather than added sequentially as might occur in a conventional approach. Once familiar with the maneuvers that maximize first pass success, the operator may choose a simpler approach. Keys to first pass success include (1) manipulation of the axial anatomy (ie, head, neck, torso positioning) to achieve optimal rather than adequate glottal exposure, (2) retention of fine motor control, through the use of assistants or physical supports for optimal position of the upper torso and head/neck, (3) effective navigation to find and control the epiglottis, and (4) early use of bimanual laryngoscopy. Each key requires practice until it is automated. Integrated performance to complete intubation within 30 seconds, as recommended for unstable patients, requires more practice.

PREPARATION FOR LARYNGOSCOPY

Careful preparation for intubation requires a mental checklist. Of many helpful pneumonic devices, the authors prefer "STOP MAID," to remember the following (Fig. 5-1):

S: Suction

T: Tools for intubation (laryngoscope blades, handle) and for difficulty with ventilation and/or intubation (laryngeal mask airway [LMA], intubating LMA, lightwand, optical stylet, etc.)



FIGURE 5-1 Intubation equipment.

O: Oxygen source for preoxygenation and ongoing ventilation
P: Positioning—shoulder roll and head elevation as high as it does not interfere with blade insertion; PLAN B: Effective airway management requires careful planning so that back up plans can be executed when the primary technique (plan A) fails.[2]
M: Monitors, including EKG, pulse oxymetry, blood pressure, end-tidal CO_2, or esophageal detectors
A: Assistant, ambu bag with face mask, airway devices (tubes, syringe, stylets)
I: Intravenous access
D: Drugs including hypnotic, muscle relaxant and desired adjuncts

Effective airway management requires careful planning so that back up plans can be executed when the primary technique fails

POSITIONING

Positioning can facilitate both blade insertion and glottic exposure. The sniffing position, most clearly defined by Horton et al[3] is atlanto-occipital extension, and elevation of the head to achieve "lower neck flexion [of] 35°," which in normal volunteers required head support of 31 to 71 mm. Further head elevation may facilitate DL and may be essential for intubation in difficult cases.[2–7] Clinical and geometric observations show flexing the thoracic spine to elevate the head may facilitate DL more than flexion of the cervical spine (Figs. 5-2–5-4).

Axial Positioning During Blade Insertion

Experienced operators typically can expose the glottis with no or minimal elevation of the patient's head and torso from the sniffing position and usually require no assistance to improve glottic view even when complex manipulations are necessary. For less experienced operators and when patient instability demands first pass success, head lift by an assistant from the initiation of DL requires less left hand force, improves sensitivity and control, and frees the right hand for external manipulation. As described by Murphy: "… the sniffing position is a starting position only… make it dynamic. Use your right hand behind the head to lift it, flex and extend the head on the neck, rotate it left and right as needed to bring the target into view. Once the best view is obtained, have an assistant hold the head in this position."[7]

Opening the Mouth

The mouth is opened widely by supporting the index, long, and/or ring fingers of the right hand against the upper teeth, and crossing the thumb down against the lower teeth (Fig. 5-5). Atlanto-occipital extension, provided by placing the right hand against the occiput of the unconscious patient, can help to open the mouth as well. Mouth opening and/or blade insertion may be compromised by retrognathism, prominent upper teeth, obesity, large breasts, short thick neck, or neck flexion. Elevation of the upper thorax as by a shoulder roll, or creation of a "ramp," can facilitate mouth opening and blade insertion by improving submandibular compliance and increasing physical separation of the chin from the chest (Figs. 5-2–5-4

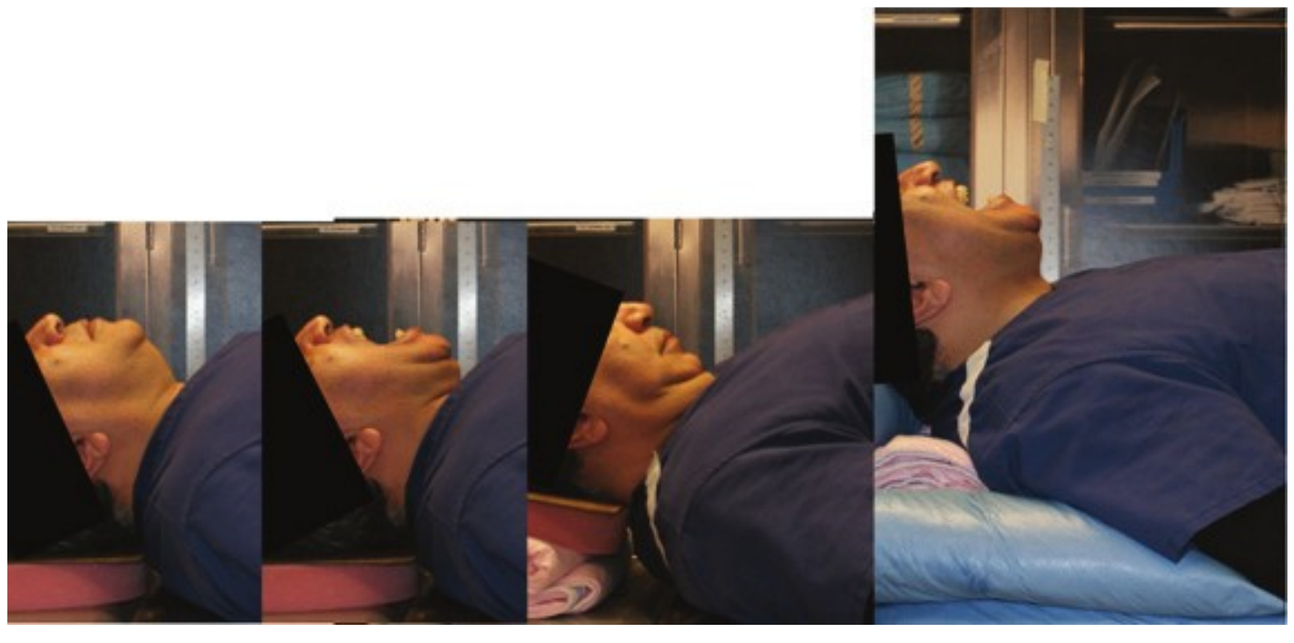


FIGURE 5-2 When a normal heavy-set individual opens his mouth the submandibular and anterior cervical spaces impinge (despite, in this example, head elevation of 5 cm). As a result, submandibular compliance is decreased (compare **A** and **B**). **C**. Impingement is made worse when head elevation is achieved by cervical flexion, especially in patients with a short neck or who are heavy-set. **D**. Flexion of the thoracic spine enables a higher head elevation relative to the chest while decreasing impingement. (Table level is the same in all photos.)



FIGURE 5-3 Value of ramp construction to facilitate blade insertion and glottic exposure is best documented in care of morbidly obese patients[1,8]. Levitan added the bar to promote elevation of the head to align the ear canal with the sternal notch. Elevation of the ear can be achieved by flexion of the neck or the chest. Geometric considerations are helpful to understand why thoracic flexion is more helpful (Fig. 5-4).

(Modified from Levitan et al with permission.)

and Fig. 5-6). Simply rotating the blade for insertion, then turning it into the correct plane, may be helpful, with care that rotation not result in torque pressure against the teeth. A short-handled laryngoscope may also be useful in these settings.

Novices are well advised to advance the blade over the right dorsum of the tongue, sufficiently close to the midline to retain orientation. Insertion along the right side of the mouth allows the vertical flange of the blade to cordon most of the tongue to the left (Fig. 5-7). When the glottis is sighted, if there remains a residual bulge of tongue on the right of the blade, pulling the right corner of the mouth laterally usually allows the glottis to remain in sight while the tube is passed below (cephalad to) the tongue mass.

Utility of Bimanual Laryngoscopy/ External Laryngeal Manipulation

Wilson and colleagues[9] were the first to quantify the value of laryngeal pressure when they used it to reduce the incidence of grade 3 and 4 views from 9.3% to 5.9%. Benumof and Cooper[10] found that the technique, which they called optimal external laryngeal manipulation, could consistently improve the laryngeal view by one Cormack-Lehane grade. Levitan[11] further reinforced the utility of this technique, referring to it as bimanual laryngoscopy. External laryngeal manipulation should be an integral part of DL and should be the first maneuver used to improve the view of the larynx (Fig. 5-8A–D).

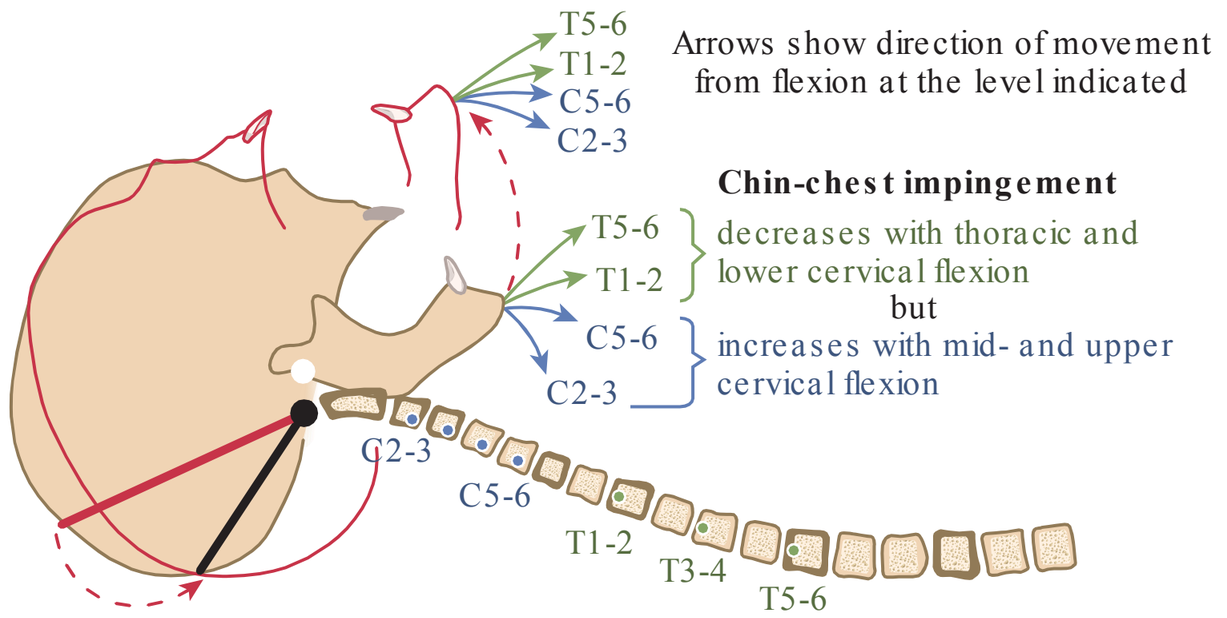
Curved Blade Technique

Easy exposure in some cases may tempt the operator to casually insert the blade first and correct its position only if necessary. A safer practice is habitual early and continued sighting of the epiglottis until the tip of the curved blade is passed above it. The epiglottis is the essential landmark for both curved blade and straight blade laryngoscopy. A more lateral approach from the right side can lower the angle "under" the tongue; contact of the flange with teeth is diminished by first maximally opening the mouth.

Optimal position of the curved blade tip on the hyoepiglottic ligament is defined by briskness of epiglottis response to light forward movement of the blade tip, or external pressure by the fingers of the right hand on the thyroid cartilage. It is helpful to have a mental image of the several blade tip positions that cause inadequate epiglottis response (see Fig. 10, in Anatomy chapter). During elective laryngoscopy in stable patients, the use of gentle bimanual laryngoscopy to learn how different blade positions affect the epiglottis and how to navigate to the "sweet spot" is a useful exercise.

Lifting Vector

The blade angle is almost vertical during initial insertion into the mouth, then it is swung forward to lift the tongue (Fig. 5-9). It is important to avoid levering back, as may seem tempting, to see "under" the tongue



A-O extension allows the mouth to open fully (from ~ 4 cm to 6 cm) and rotates the point of contact with the table to a point further from the rotation center (black dot). This elevates the rotation center (from the black to the red dot), which requires the spine to flex.

FIGURE 5-4 Effect of axial manipulation on glottic exposure: Atlanto-occipital (a-o) extension, and cervical vs. thoracic flexion.

A-o extension (indicated by red upper and lower incisors) facilitates DL by several mechanisms. 1. Reduced tissue impingement allows the mouth to open maximally and improves compliance of the submandibular space. 2. Blade insertion is facilitated by moving the mouth away from the chest. 3. Flexion at every level is more effective because flexion arcs are rotated upward. 4. The upper spine is elevated, which requires spine flexion. The spine is elevated because the distance between the a-o rotation center (black dot) and table surface is increased (black and red lines); this elevation of the spine requires spine flexion just as does elevation on a pillow.

Level of flexion. The effect of head elevation on DL depends on the level at which flexion occurs: Head elevation requires flexion of the spine, which can occur anywhere from C2-3 to the lumbar spine. Geometric considerations suggest that whether submandibular compliance improves or is made worse depends on where flexion occurs. The black figure indicates the spine in a neutral position; mouth opening is limited by impingement of submandibular and anterior cervical tissues. Arrows arcing from the chin indicate movement due to flexion at the levels indicated. Flexion of the C spine (C2-3 - C5-C6) increases impingement below the chin and causes the trachea to slide into the thoracic inlet. The tissue beds are increasingly separated by flexion lower in the spine, due to greater radius as well as more vertical arc.

(Fig. 5-10). Resistance to soft tissue displacement as upward force is applied is best addressed by lifting the head, which is accompanied by a rotation forward of the lift vector and often an improved view of the glottis.[3-7]

Straight Blade Technique

A no. 2 Miller blade is adequate for most adults.[12] The essence of straight blade laryngoscopy is to place the blade tip underneath the epiglottis, then lift it to reveal the glottis. The tip of the blade may thus be advanced into the superior-most portion of the laryngeal inlet before retraction actually begins.

As with the curved blade, the epiglottis is identified in the straight blade technique and secured in a controlled, deliberate manner. Exposing the glottis accidentally after inserting the blade to the presumed correct depth may lead to blind probing and should be discouraged. The narrow tip of the Miller blade readily penetrates the posterior hypopharynx, and the trauma may not be apparent in many cases until manifested as deep neck infection or sepsis.[13] In addition, if the larynx is inadvertently bypassed, retraction with the laryngoscope may reveal the orifice of the proximal esophagus, which can appear deceptively "airway-like" (see Fig. 5-11).



FIGURE 5-5 **A:** Mouth opening using fingers in a "scissors" configuration. **B:** Mouth opening using head extension.



FIGURE 5-6 For obese patients, a "ramp" of blankets, or commercially available foam wedge, allows the patient to more effectively adopt a "sniffing" position, enabling laryngoscope blade insertion and effective DL.



FIGURE 5-7 Sweeping tongue to left with laryngoscope blade.

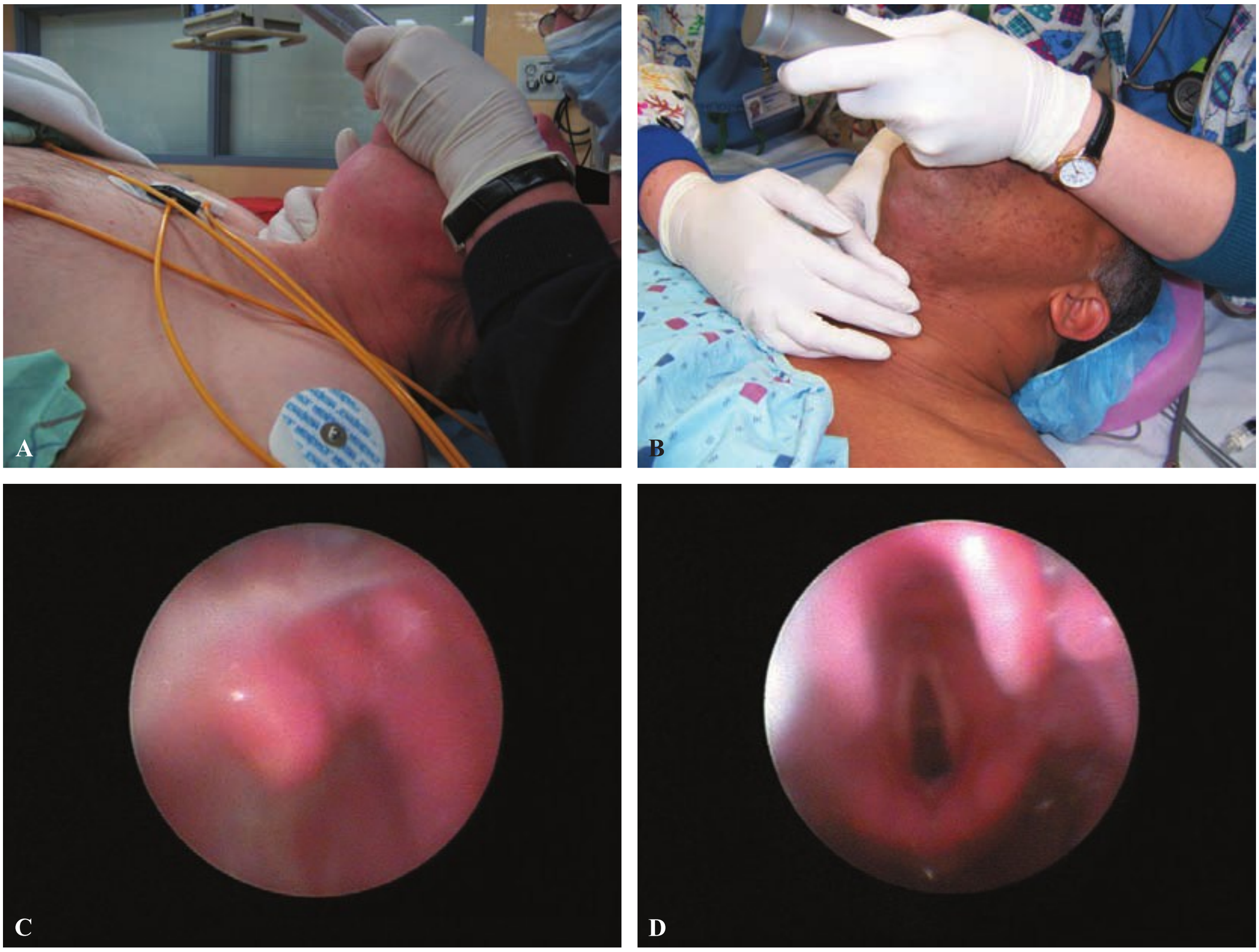


FIGURE 5-8 **A:** External laryngeal pressure by operator. **B:** Assistant taking over ELM from operator. **C:** View of glottis without external laryngeal pressure. **D:** View of glottis with external laryngeal pressure.

FIGURE 5-9 Direction of forces applied for DL





FIGURE 5-10 Inappropriate "levering" force in DL. Note pressure of flange of Macintosh blade against upper lip and teeth.

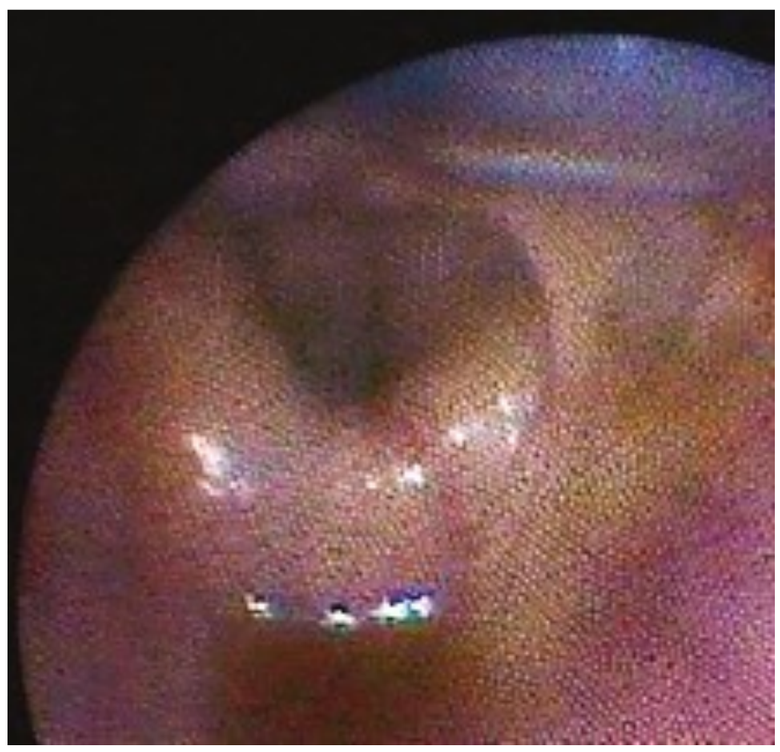


FIGURE 5-11 Glottis-like appearance of esophageal opening when blade is passed below and lifts larynx. Mucosal folds cam be mistaken for posterior cartilages, a fold of mucosa can simulate a vocal cord or aryepiglottic fold, and a pool superior to the orifice can be mistaken for a pool obscuring the opening to the esophagus.

Straight blade lift vectors are similar to those of curved blade laryngoscopy. After initial near-vertical insertion, the handle and angle are lowered to pass under the tongue, and may be lowered further as the blade is advanced; but the temptation to lever back on the laryngoscope blade must be avoided. Difficulty with soft tissue displacement should be addressed by lifting the head, which rotates the lift vector forward and often improves the view of the glottis, as noted in the section on curved blade technique. Also as with the curved blade, midline insertion of the straight blade facilitates orientation, but glottic exposure in difficult cases benefits from a more lateral right-sided, or "paraglossal," approach.

Henderson[14] reviewed the paraglossal technique and described successful use of the Miller blade in 10 patients in whom the view of the glottis was poor with the Macintosh blade. Achen[15] noted that the paraglossal technique with the Miller blade provided a higher proportion of full laryngeal exposure than the Macintosh blade among 160 anesthetized patients. The low vertical profile and narrow spatula of the Miller blade can be particularly useful in this relatively cramped region of the oral cavity. When mouth opening admits a higher flange, there are advantages to the Phillips and Henderson blade designs (Figs. 5-12 and 5-13).

When an appropriate view of the larynx is established, the ETT is placed, inserting it from the right side of the mouth, with as little interference of the line of sight as possible. The lips often are more of an impediment to the extreme rightward approach than in a more midline approach, or in curved blade laryngoscopy, and use of an assistant to retract the lip permits easier insertion of the tube.

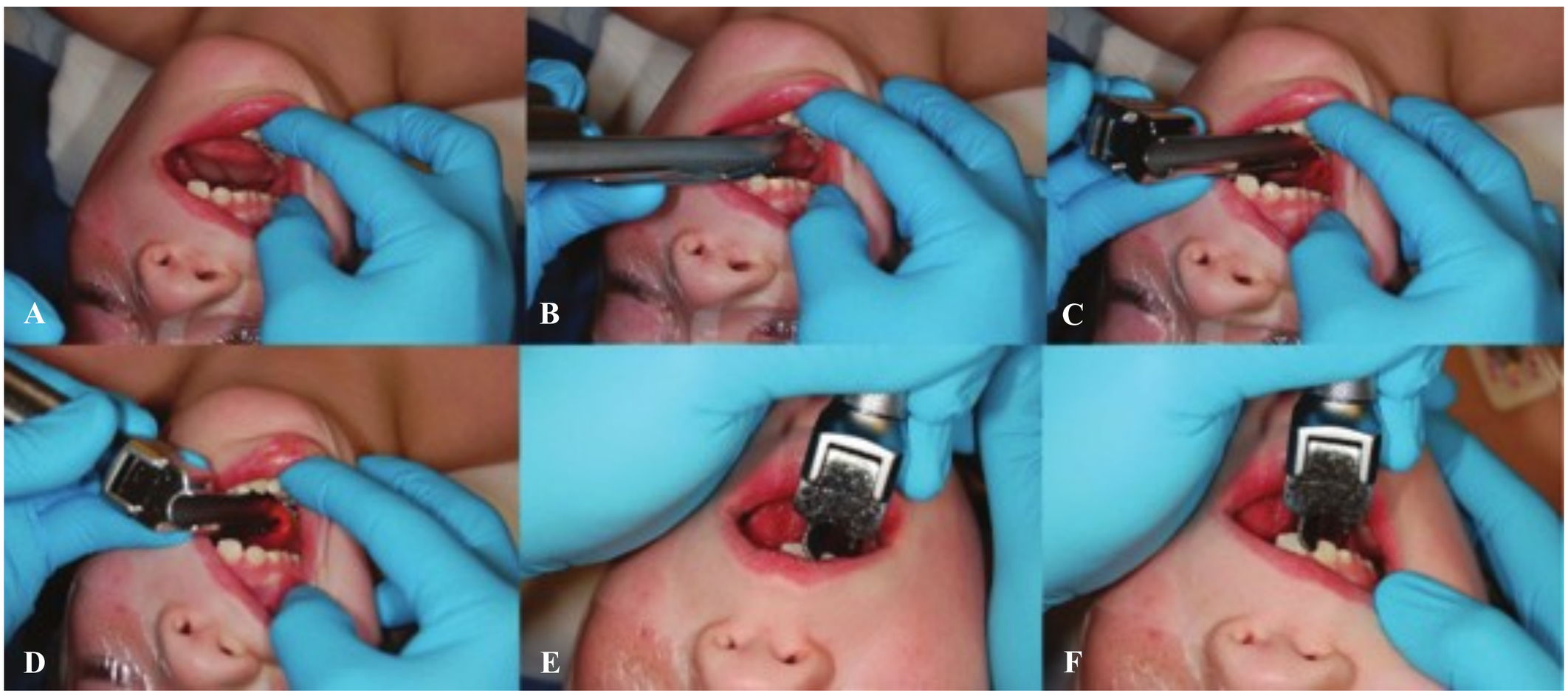


FIGURE 5-12 Paraglossal straight blade approach. Tongue control and gutter entry is initiated by crossing from the left to enter the right gutter **(B, C, D)**, then advancing only to the right anterior pillar. Pharyngeal landmarks are sought by rotating the blade tip to the left **(E)**. The blade tip is advanced under the epiglottis and lifted to expose the glottis, then the blade is moved toward the midline to displace the tongue and make room for the ET (F).
(Borland, personal communication.)

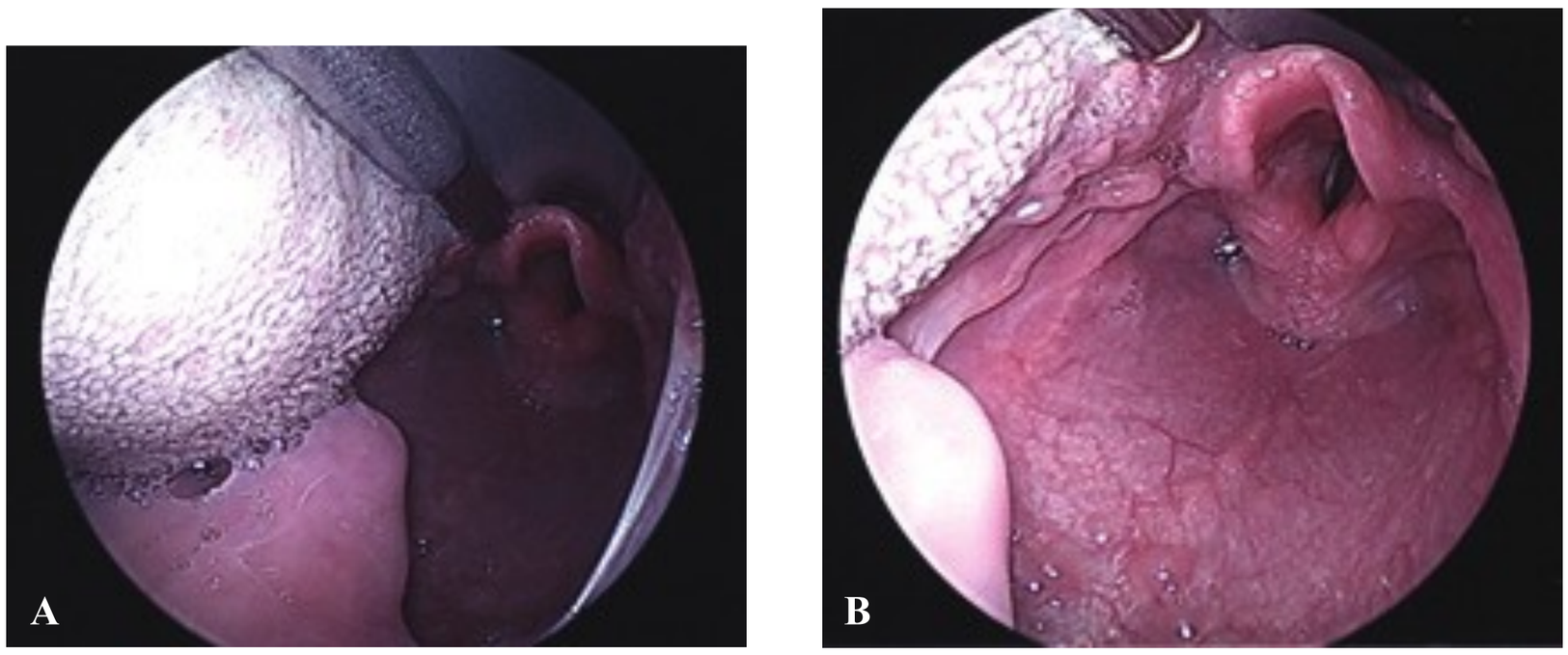


FIGURE 5-13 Paraglossal laryngoscopy (Phillips blade): "Advance to anterior pillar and look left." The glistening sharp edge on the right (A: between 3 and 5 o'clock) is the right anterior tonsillar pillar. Placement of the uvula at 6 to 9 o'clock and follicular tongue to the left accentuates this blade coming in from the gutter on the right side of the tongue. Bulb position on the left side of this no. 1 Phillips blade helps avoid crowding in this technique and catching or ripping the ET or cuff. In this pediatric patient the blade tip is anterior to the epiglottis, as commonly is effective in children but not adults.
(Navigation and figure courtesy of L. Borland.)

Straight Blade versus Curved Blade

A lateral approach is required for difficult cases with either blade. A smaller viewing port (Miller blade) and reduced area in which to manipulate the tube (far right corner or paraglottic approach), can make tube insertion with the straight blade more challenging than with an adequate curved-blade laryngoscopic view. However, straight blades require less anterior displacement of the hyoid bone for a given line of sight, and the paraglossal approach allows a lower angle of approach. Straight blades are recommended to reduce trauma to friable pathology at the base of the tongue, such as hypertrophic lingual tonsils.[16] Comparison studies have indicated straight blade success after curved blade failure; we are not aware of the opposite finding.[14,15]

The amount of lifting force required to expose the glottis maximally is related to some known variables: the heavier the patient, the greater is the force required,

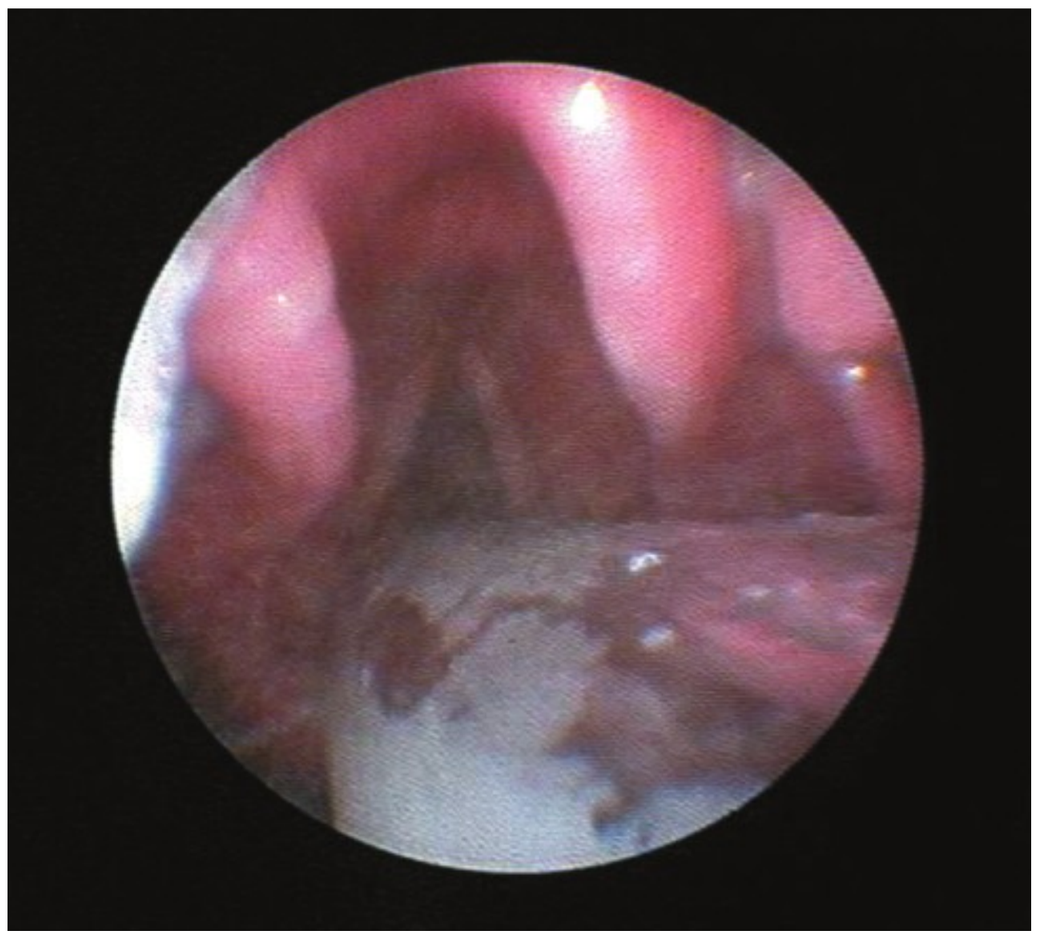


FIGURE 5-14 ETT insertion.

and the lifting force required is less with a straight blade than with a curved one.[17,18] Hastings et al[18] evaluated force required for laryngeal exposure with a size 2 Miller blade and a size 3 Macintosh blade in 17 patients, and found that the Miller blade required 30% less lifting force; the view was similar with both blades in 10 patients, whereas it favored the curved blade in three patients and the straight blade in four.

Despite these possible advantages of a straight laryngoscope blade, most physicians prefer to initiate laryngoscopy with the curved blade. Its larger spatula permits greater area for both viewing and manipulation of the tube, as does its vertical flange. The "feel" of a curved blade is more anatomic as it curves along the tongue and seats in the vallecula. Frequent departure from this comfort zone is recommended to maintain skill with an alternative straight blade.

ETT PLACEMENT

Once the glottic view is revealed, and found to be adequate, the ETT is placed between the vocal cords with the right hand (Fig. 5-14). Attempts at laryngoscopy may become quite involving, and the laryngoscopist may easily lose track of the duration of patient apnea. Laryngoscopy attempts should generally be limited to 30 seconds, or the occurrence of oxygen desaturation, whichever comes first. Note that SpO_2 technology results in at least 30 seconds delay in readout. Particularly in critically ill patients, rapid desaturation may occur due to inadequate time for preoxygenation, atelectasis with shunting, or cardiopulmonary pathology. Thus it is imperative to use bag mask ventilation (see Chapter 2) to achieve the highest possible oxygenation between every attempt at laryngoscopy.

During intubation, as the tube is advanced into the mouth and pharynx, every attempt must be made to avoid placing it into the operator's line of sight. Rather, the tube should enter the mouth lateral to the blade, and pass close to the palate below the line of sight, then manipulated so the tip appears from below at the glottic opening.

Emergent intubations should be carried out with a stylet in place in the ETT. Once the tip of the tube has passed the vocal cords, the stylet may contribute to tracheal damage. At this point, the laryngoscopist should hold the ETT firmly and keep the laryngoscope in place, observing that the tube is not dislodged, as an assistant removes the stylet. Although the angle to which the ETT-stylet combination is bent is an individualized decision, it has been shown that an angle of less than 35° seems to facilitate passage of the ETT beyond the glottis.[7]

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CHAPTER 6

Confirmation of Endotracheal Tube Placement

Brian Blasiole and Tetsuro Sakai

A misplaced endotracheal tube (ETT) can result in severe morbidity and mortality. As soon as an ETT is inserted, its presence in the trachea must be confirmed. A quick method to confirm ETT placement is to directly visualize the ETT as it passes through the vocal cords. Video laryngoscopes have improved the approach of visualizing the airway (Fig. 6-1A, B)[1]; however, a view of the glottis may often be obscured despite the technique of visualization used. As no single test exists that definitely establishes correct placement of the ETT, confirmation should best be carried out with a combination of physical examination maneuvers and CO_2 detection.

Detection of exhaled CO_2 is widely accepted as the most reliable, readily available technique of confirming ETT placement. This is accomplished either with capnography (continuous monitoring of end-tidal CO_2, which is displayed graphically on a dedicated monitor) (Fig. 6-2A) in operating rooms or with a small, portable end-tidal CO_2 detector (a purple-to-yellow color change indicates presence of >4% CO_2 in exhaled gases) (Fig. 6-2B, C) outside of operating rooms. Although CO_2 detection reliably localizes the ETT in the airway, it does not distinguish between tracheal and endobronchial intubations. Furthermore, both false-negative and false-positive results may occur.[2] Even with correct ETT placement, exhaled CO_2 will be near 0 in patients with severe bronchospasm, cardiac arrest, or markedly diminished pulmonary blood flow despite correct placement of the ETT. Other confirmation methods are preferred in these situations. It should be noted that, during esophageal intubation, CO_2 can be detected from gases present in the stomach or esophagus. Detection of such CO_2 usually rapidly diminishes over four to five attempts at ventilation. If end-tidal CO_2 is detectable and stable (not diminishing) thereafter, the ETT is almost certainly in the airway.[3]

When no means of CO_2 detection is available or CO_2 detection is unreliable (ie, cardiac arrest), the esophageal bulb detector device can provide a means to ascertain whether the ETT is in the airway or in the esophagus for patients older than 1 year of age (Fig. 6-3A, B). As the trachea (and bronchi) possesses cartilaginous walls and contains a column of air, a collapsed bulb device attached to the proximal end of an ETT that is in the airway should suction air and be rapidly reinflated. On the other hand, if an ETT is placed in the esophagus, the deflated bulb device remains collapsed because the negative pressure generated by the device apposes the esophageal walls.[4]

Physical examination should always be performed in conjunction with the above methods for the confirmation of an ETT placement (Figs. 6-4 and 6-5). These include auscultation of chest (which is best carried out in the bilateral axillae) (Fig. 6-5) and upper abdomen (appreciating sounds of gastric insufflation), as well as observation for evidence of chest rise and the absence of gastric distension. Additional physical signs of appropriate tracheal intubation include the appearance of vapor in the ETT during exhalation and "balloting" of the ETT cuff above the sternal notch while palpating the pilot balloon of the ETT (Fig. 6-4).[5] None of these methods is entirely reliable, but in combination with CO_2 detection (or the esophageal bulb detector, if CO_2 is not likely to be present), these physical examination maneuvers should nearly eliminate the possibility of esophageal intubation.

Several imaging modalities can be used for further confirmation of ETT placement. Postintubation chest radiography can contribute to ETT localization. Anterior-posterior X-ray can be used as a tool to estimate the depth of ETT insertion and to rule out bronchial intubation. However, the lateral film is more reliable in detecting esophageal intubation because superimposition of an esophageal ETT over the trachea can be misleading. Although frequently unavailable outside of the operating room or critical care unit, fiberoptic bronchoscopy is a highly accurate method to ascertain correct ETT position[6] as it provides direct visualization of the ETT and its location. Ultrasonography is a newer method to determine ETT position. It can provide direct visualization of a styletted ETT during placement in the trachea.[7] Transthoracic ultrasonographic imaging of diaphragmatic and pleural motion with lung expansion can provide indirect evidence of correct ETT position.[7]

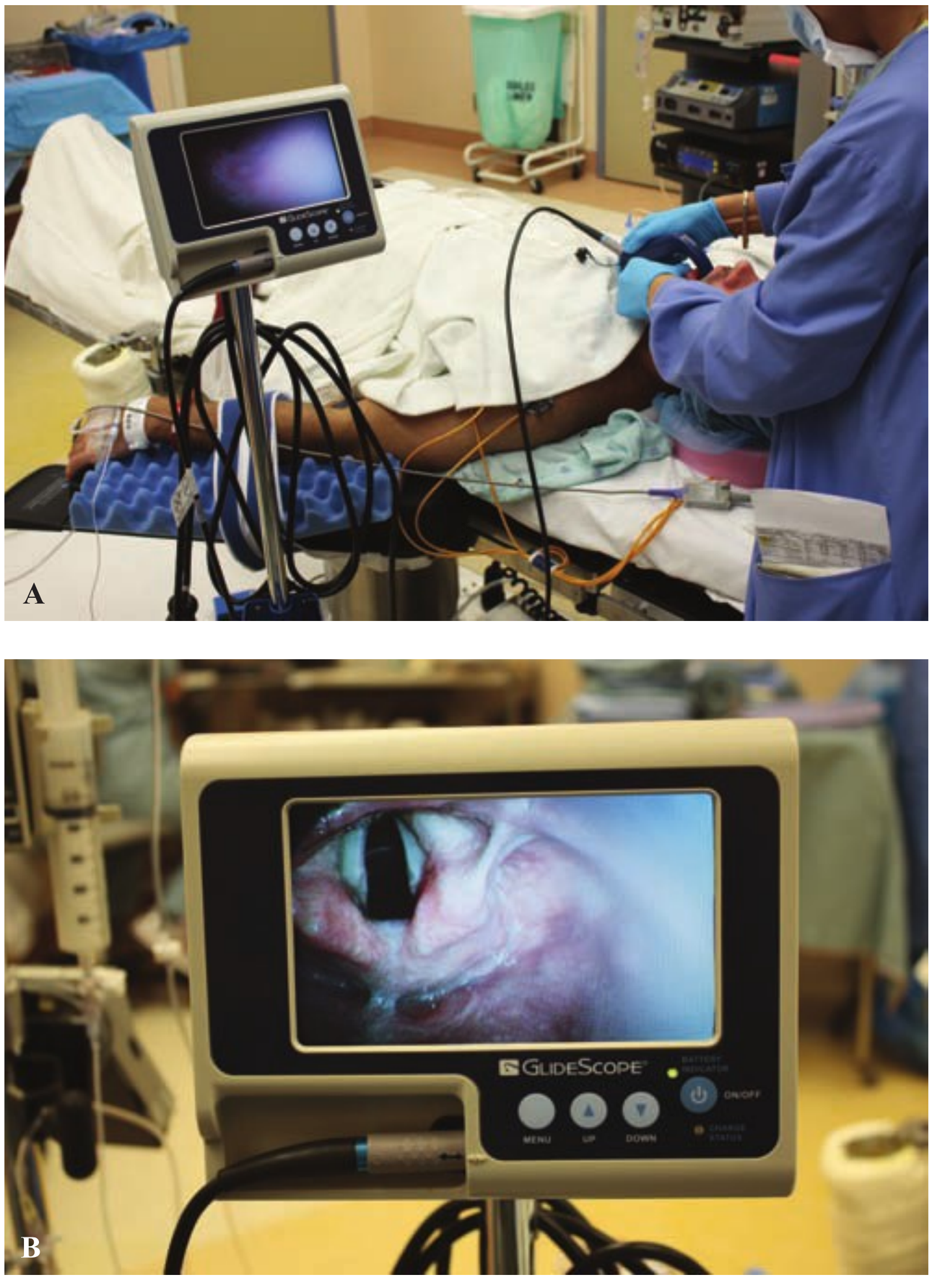
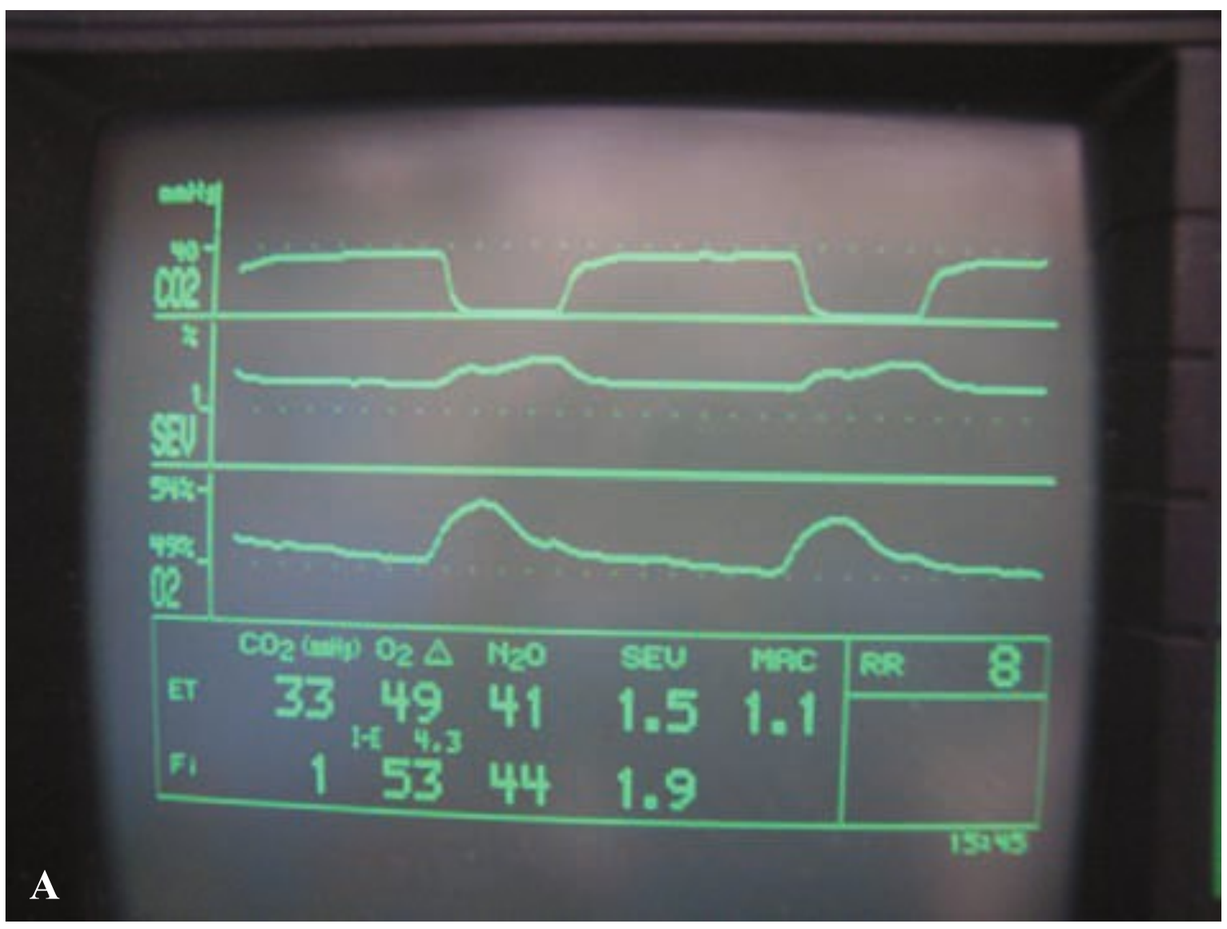


FIGURE 6-1 GlideScope Video Laryngoscope (GVL; Verathon, Bothell, WA, USA). **A:** Anesthetist visualizing the glottis using the GVL. **B:** View of the glottis using the GVL.





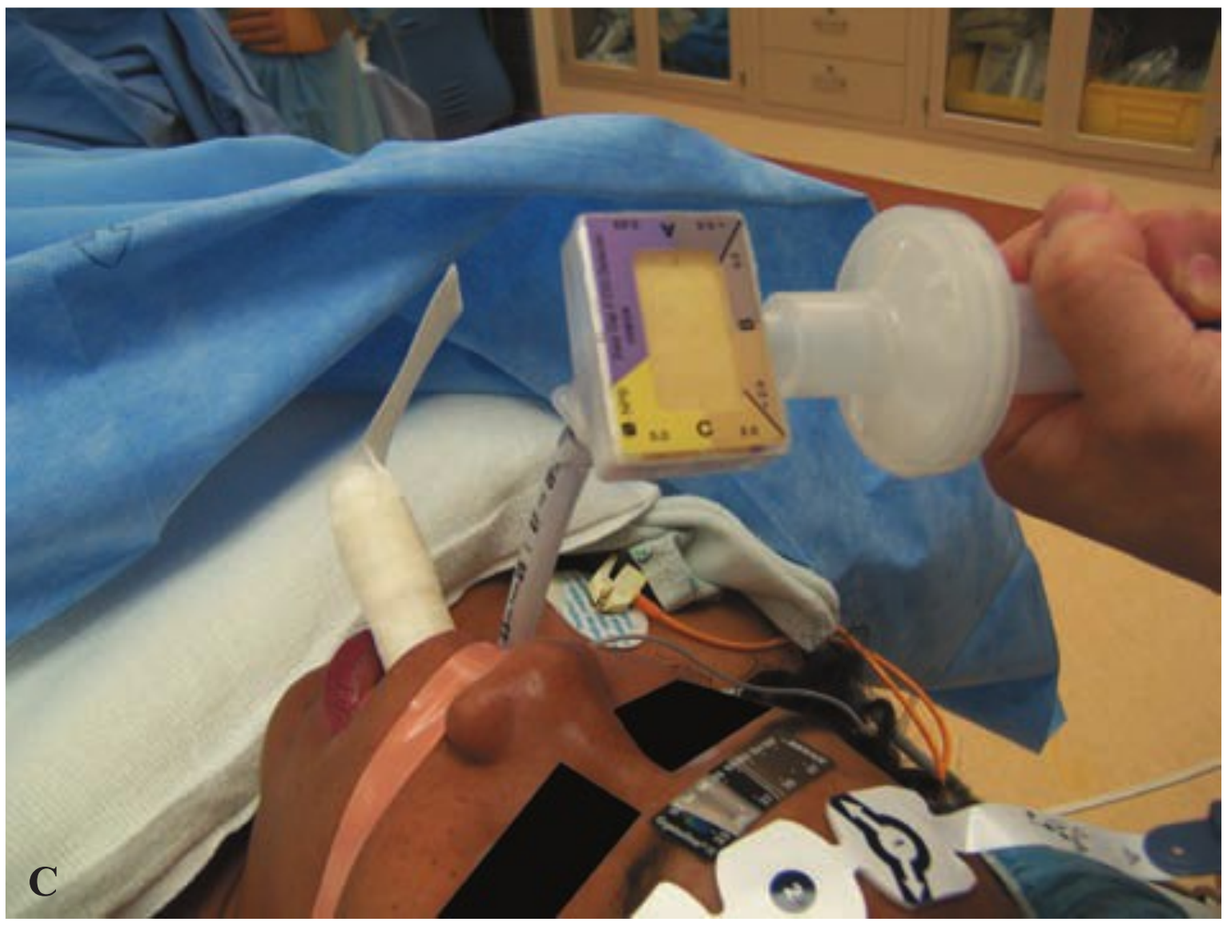


FIGURE 6-2 **A:** Capnography in the operating room. **B:** CO_2 color-change indicator: purple color before connection to circuit. **C:** The indicator turns yellow when connected to the circuit, indicating correct ETT placement.

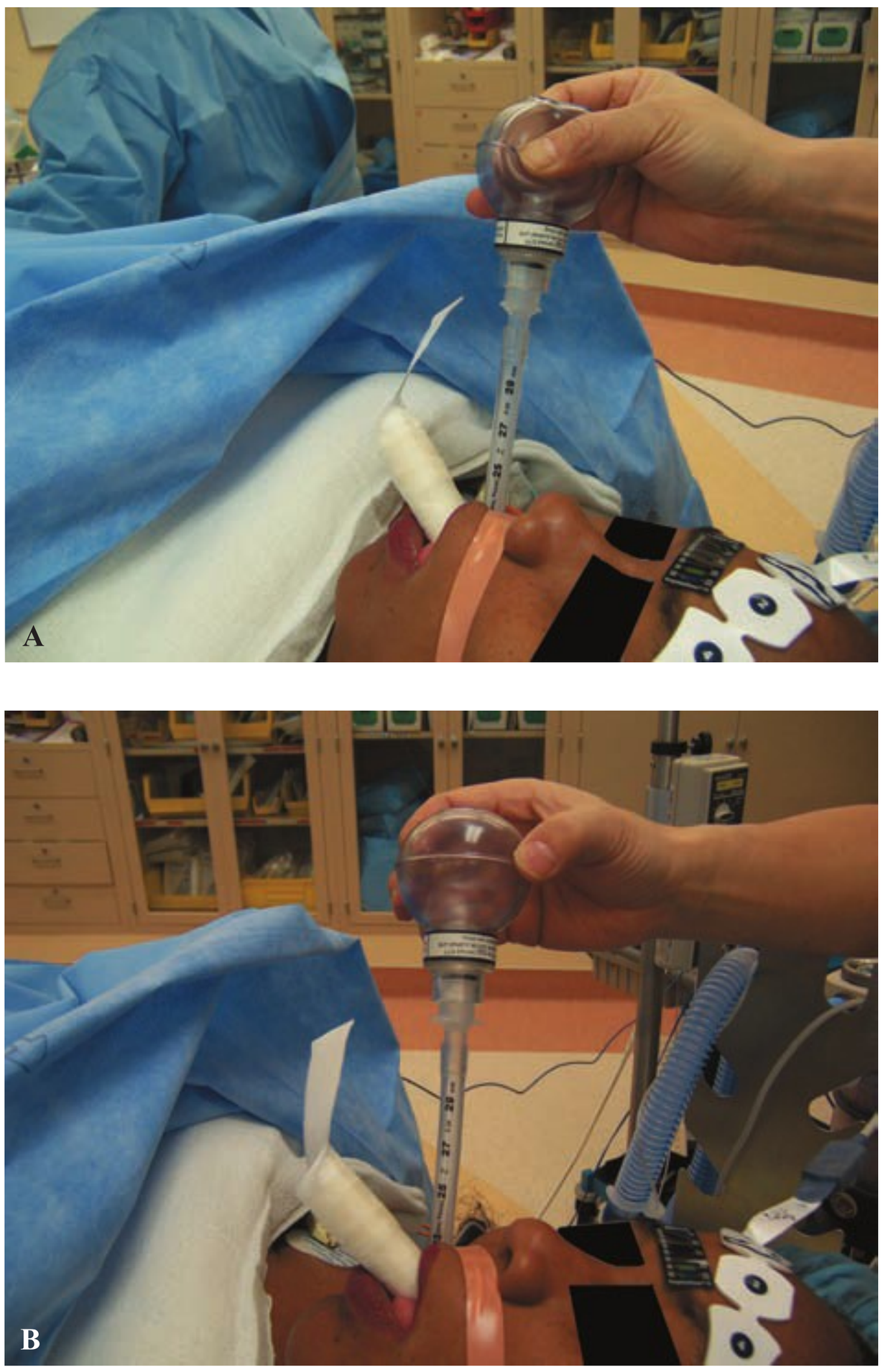


FIGURE 6-3 **A:** An esophageal bulb detector device. **B:** When placed on the end of the ETT, and deflated, it should reinflate if the ETT is in the trachea.



FIGURE 6-4 "Balloting" the ETT cuff in the trachea while palpating the pilot tube.



FIGURE 6-5 Auscultation in the axillary area contributes to confirmation of ETT placement.

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CHAPTER

7

Pharmacology for Airway Management

Daniel Cormican and Shawn Beaman

Medications are used in most airway management situations, and as such, familiarity with the common drugs and dosages used is crucially important. The basic premise of medication use in airway management is to create optimal conditions for the requisite airway intervention while maintaining the patient's safety. Different airway situations require different medications and optimization can have various forms, which always include maintaining oxygenation, maintaining hemodynamic stability, and blunting the sympathetic response to the airway intervention. Other goals include keeping the patient as comfortable as possible and relaxing skeletal muscle when appropriate. Pharmacologic intervention prior to airway management should be tailored to the specific needs and current clinical conditions of each patient. Inappropriate use of many of the medications mentioned in this chapter can actually cause the patient harm.

In controlled, elective airway management situations—for example, placement of endotracheal tube for elective surgery—the first medication administered is often an anxiolytic and/or analgesic (Table 7-1).[1] This helps decrease the anxiety and fear commonly reported before surgical procedures. Oxygen is then provided to help maintain necessary blood oxygen content for homeostasis during the expected period of apnea that occurs after administration of intravenous (IV) general anesthetic agents (Table 7-2) and muscle relaxants (Table 7-3), which are provided to render a patient unconscious and paralyzed, respectively, for the planned airway intervention. Note that the anesthetic must be administered before the muscle relaxant so as to avoid the patient experiencing total paralysis while awake. The combination of anesthesia and paralysis serves an important role in optimization of conditions for intubation—movement is decreased, the patient is amnestic to the event, the vocal cords are relaxed and open, and the cough and gag reflexes are diminished.[2] In routine anesthetic practice, in the elective case, the most commonly used IV anesthetics are propofol and sodium thiopental. Muscle paralysis improves intubating conditions by causing the relaxation of head and neck musculature and preventing the patient's reflexive movements during direct laryngoscopy. Paralysis is frequently obtained with succinylcholine, which has rapid onset and a brief duration of action. In cases where succinylcholine is contraindicated or avoidance of its side effects is desired (Table 7-4), a nondepolarizing neuromuscular blocker such as rocuronium or vecuronium is often used.[3] It should be noted that neuromuscular blockade is not always used in preparation for perioperative airway management—such medication is not used during any awake airway management interventions because continued spontaneous respiration is desired, and avoiding use of neuromuscular blockade may be appropriate in certain cases where overall patient outcome might be jeopardized with its use (eg, procedures where motor function is to be monitored or patients with myasthenia gravis).[4]

As with adults, optimal airway conditions are sought in children undergoing surgery (see Chapter 40). This is frequently carried out not with IV medications but rather with inhalational anesthetic gases. Sevoflurane is the most commonly used agent for inhaled induction of anesthesia because of its rapid onset and comparatively less pungent and irritating characteristics. In either adult or pediatric patients, it is important to be mindful of the expected alterations in hemodynamics and respiration after administration of sedatives, analgesics, and general anesthetics.[5]

Emergent airway management situations may require different medications from those used in elective cases. In situations requiring emergent intubation of a conscious patient, IV hypnotics are routinely administered to render a patient unconscious, as they are in a controlled elective situation. However, attention must be paid to the overall presentation of the patient requiring immediate airway intervention. In hemodynamically stable patients with presumed euvolemia, both propofol and sodium thiopental can be utilized to provide rapid loss of consciousness. Those patients with an uncertain volume status and/or tenuous hemodynamic stability are often administered etomidate, because it is the IV hypnotic least likely to cause a change in the patient's heart rate or blood pressure. Patients with frank shock, hypovolemia, and/or unstable hemodynamics are most appropriately managed with ketamine as it has indirect sympathomimetic properties. Intubation of unconscious patients who are moribund frequently requires no medication administration for airway intervention as the severely compromised hemodynamics

Table 7-1

Agents Used for Preoperative or Preprocedural Sedation/Analgesia in Adults[1]

Agent	Dose	Effect
Midazolam	0.5–2 mg IV	Anxiolysis, amnesia
Diazepam	2.5–5 mg IV	Anxiolysis
Fentanyl	25–100 mcg IV	Sedation, analgesia
Morphine	2.5–5 mg IV	Sedation, analgesia

Table 7-2

IV General Anesthetic Agents for Induction of Anesthesia[1]

Agent	IV Dose (mg/kg)[a]	Time to Onset (s)	Duration of Action after Induction Dose (min)
Propofol	Adults: 2–2.5 Pediatrics: 2.5–3.5	30	5–10
Sodium thiopental	Adults: 3–5 Pediatrics: 4–7	30	5–10
Etomidate	Adults: 0.25–0.3 Pediatrics: 0.3–0.4	15–45	3–12
Ketamine	Adults: 1–3 Pediatrics: 2–4	45–60	10–20

[a]As with all medications, dosing must be individualized to each patient. In particular, elderly patients may require significantly less medication to achieve the desired effect.

Table 7-3

Commonly Selected Muscle Relaxants for Airway Management[7]

A gent (Category)	Intubating Dose (IV) (mg/kg)	Time to Onset	Duration (min)
Succinylcholine (depolarizing)	Adult: 1.5	45 s	7–8
	Pediatrics: 2[a]	45 s	7–8
Vecuronium (nondepolarizing)	0.1	2.5–3 min	30–45
Rocuronium (nondepolarizing)	0.6–1.2	1 min	30–45
Pancuronium (nondepolarizing)	0.06–0.1	3–4 min	60–100
Cisatracurium (nondepolarizing)	0.15–0.2	2–3 min	40–60

[a]Succinylcholine is rarely given to infants or young children, given the risk of severe bradycardia. If given to this population, it is often administered with atropine 10–20 mg/kg.

Table 7-4

Adverse Responses and Contraindications to Succinylcholine[8]

Adverse Responses	Contraindications
Muscle fasciculation	Known allergy/sensitivity
Myalgias	History of/risk of malignant hyperthermia
Masseter muscle hypertonicity/spasm	Hyperkalemia
Hyperkalemia (can lead to dysrhythmia/cardiac arrest)	Muscular dystrophy or myopathy
Increased intraocular pressure	Lower motor neuron paralysis[a]
Increased intracranial pressure	Upper motor neuron paralysis[a]
Allergic reaction (hives, anaphylaxis)	Major burn[a]
Malignant hyperthermia	Known enzymatic deficiency (pseudocholinesterase deficiency)
Bradycardia	
Prolonged blockade (phase 2 block/enzyme deficiency)	

[a]Risk of adverse effect is increased 24 h after acute insult onset.

may be catastrophically worsened if sedatives, analgesics, or hypnotics are administered in this setting.[2] The patient in cardiac arrest likewise requires no pharmacologic intervention in order to place the endotracheal tube.

Special attention should be given to the patient requiring emergent intubation who has not fasted or whose gastric volume status is uncertain. A full stomach should be assumed in patients whose recent intake is uncertain, especially those with intestinal obstruction, those who come to the hospital as trauma victims, and pregnant patients. These patients are at considerable risk for emesis or passive regurgitation during the airway intervention process—the combination of a full stomach, lying supine, positive pressure ventilation for preoxygenation, and muscle paralysis can create a "perfect storm" for regurgitation of gastric contents into the mouth and subsequently the airway and lungs. As a means to avoid aspiration, rapid sequence intubation (RSI) is often undertaken. Important RSI variations from the elective situation include application of cricoid cartilage pressure *before* administration of airway management medications and the administration of drugs quickly and sequentially without attempting to mask ventilate the patient at any point in the airway management process.[3] Of historical note, the technique has undergone evolution since its inception (eg, Drs. Safar and Stept described application of cricoid pressure *after* administration of IV anesthetic)[6]; Table 7-5 outlines in full the current standard sequence for RSI as it compares to induction for elective intubation. In some circumstances, premedication before rapid sequence induction may serve to reduce adverse responses to drugs or the physical manipulations of the airway. These include administration of lidocaine to blunt the impact of intubation on elevated intracranial pressure, opioids to reduce the hemodynamic response to laryngoscopy and intubation, or pretreatment with a small dose of a nondepolarizing neuromuscular blocking agent to reduce muscle fasciculations from succinylcholine.

Beyond the aforementioned common scenarios, familiarity with other adjunctive pharmacology can be of benefit. There are situations in which standard endotracheal intubation is not appropriate, and other airway management methods and medications must be used. It is important to briefly address the common medications (Table 7-6) that are used to facilitate the performance of two of the common alternative airway techniques available to physicians: nasotracheal intubation and awake fiberoptic intubation (see Chapters 18 and 8). Many other techniques are available, and these will be reviewed throughout the remainder of this book.

Table 7-5

Comparison of Induction Sequences: Elective Intubation and Rapid Sequence Intubation[1]

Elective Intubation Sequence

1. Preparation (medications, suction, IV access, equipment)
2. Preinduction sedation (if required)
3. Placement of patient monitors
4. Preoxygenation via face mask
5. Administration of anesthetic induction agent
6. Mask ventilation
7. Administration of muscle relaxant
8. Mask ventilation
9. Direct laryngoscopy
10. Placement of endotracheal tube
11. Confirmation of correct tube placement in trachea
12. Fixation of endotracheal tube

RSI

1. Preparation (medications, suction, IV access, equipment)
2. Placement of patient monitors
3. Preoxygenation via face mask
4. Provision of cricoids pressure by assistant
5. Administration of induction agent
6. Administration of muscle relaxant
7. Direct laryngoscopy
8. Placement of endotracheal tube
9. Confirmation of correct tube placement in trachea
10. Release of cricoid pressure
11. Fixation of endotracheal tube

Table 7-6

Local Anesthetics for Airway Management[1,9]

Airway Procedure	Agent (Route of Administration)	Common Dosage/ Concentration	Effect of Agent
Nasotracheal intubation	Phenylephrine (topical nasal spray)	0.25–0.5%	Vasoconstriction, mucous membrane shrinkage, tachycardia
Awake oral fiberoptic	Glycopyrrolate (IV)	0.2 mg	Antisialagogue
	Lidocaine (transcutaneous nerve block)	2 mL of 2%	Local anesthetic
	Lidocaine (topical to oral mucosa)	3%	Local anesthetic
	Dexmetetomidine (IV)	Loading dose: 1 mcg/kg given over 10 min, followed by infusion of 0.3 mcg/kg/min	Sedation

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CHAPTER 8

Regional Anesthesia Blocks for Awake Intubation

Nikhil Bhatnagar and Steven Orebaugh

INTRODUCTION

In the American Society of Anesthesiologists difficult airway algorithm, awake intubation is the mainstay of airway management in situations where standard induction and intubation of a patient may be lethal. In these patients, a successful awake intubation requires a skilled and experienced physician capable of properly preparing a patient. If done correctly, the psychological and physical trauma of the procedure is virtually eliminated.

The bulk of this chapter is dedicated to the anatomy of the upper airway as well as the various regional techniques used when topicalizing the upper airway. It should be noted that any combination of these techniques can be used and that not all of these techniques need to be performed when topicalizing a patient. The choice of which techniques to use is based not only on indications and contraindications to the procedure but also on the skill and experience of the anesthesiologist performing these procedures.

PREPARATION

Even before anesthetizing the airway, there are several steps that will need to be carried out in order to ensure a successful awake intubation.

Consent

Awake intubations are one of the most terrifying and bewildering procedures a patient can experience. Explaining the procedure as well as explaining why the procedure is being performed will considerably help the patient to psychologically prepare for the procedure.

This is also the time to assess whether the patient will be able to fully cooperate. The patients most at risk are the very young, very old, and the mentally handicapped. Remember the one absolute contraindication to awake intubation is patient refusal or an inability to cooperate.

Antisialogogues

Decreasing secretions will help with visualization when doing an awake intubation. In addition, antisialogogues facilitate the efficacy of local anesthetics by enhancing absorption of local anesthetics at the site of action and by decreasing dilution of the local anesthetics.

Common drugs used are anticholinergics like atropine 0.5 to 1.0 mg or glycopyrrolate 0.2 to 0.4 mg intramuscularly or intravenously.

Intravenous Sedation

Judicious use of sedation is imperative in order to achieve appropriate anxiolysis. The choices for sedation are numerous, and there are a few rules to follow to maintain patient safety when preparing the patient for an awake intubation.

The main rule is to use small amounts of sedation and not to use several different types of sedation. The reason for this is two-fold. The first reason is that overly sedating a patient can result in apnea, there by converting a controlled airway to an uncontrolled emergency airway. The second reason is that oversedation results in loss of what little airway reflexes are left after topicalization, leading to an increased risk of aspiration.

Although not a comprehensive list, here are the main classes of drugs used for sedation.

1. Benzodiazapines—midazolam, lorazepam, and diazepam are examples. Midazolam is the most commonly used in this class because of its short duration and rapid onset. When used alone, benzodiazepines do not cause the loss of airway reflexes and apnea commonplace with other classes of drugs. It should be noted that when benzodiazepines are combined with opioids, there will be a synergistic effect on respiratory depression.
2. Opioids—fentanyl, remifentanil, morphine, and dilaudid are examples. Fentanyl is the most commonly used in this class. Although effective for pain control as well as ablating the cough reflex, opioids are notorious

for depressing respiration and should be used in smaller amounts.

3. *N*-Methyl-D-aspartic acid antagonist—ketamine is the main drug in this class. It has the advantage of sedation and pain control, without as much respiratory depression as other classes of drugs. It should be noted that ketamine can cause hypertension and tachycardia. In addition, ketamine has the well-known side effects of excessive salivation as well as hallucinations; so glycopyrrolate and midazolam should be used in conjunction with ketamine.
4. Alpha 2 antagonist—dexmedetomidine is the main drug in this class. A relatively new drug, this drug has the advantage of sedation and pain control without the respiratory depression. When bolused, this drug causes an initial hypertension followed by hypotension. Bradycardia is also a common problem with this drug.

LOCAL ANESTHETICS

The oropharynx, nasopharynx, and larynx are all highly innervated, sensitive structures. As a result, instrumentation of these areas would be impossible without the use of local anesthetics in the awake patient. Historically, several types of local anesthetics have been used for this purpose; but in modern practice, only three local anesthetics are used regularly when topicalizing the airway.

1. Lidocaine—this amide local anesthetic is by far the most versatile local anesthetic used by anesthesiologists. It has many preparations including IV, topical, and aerosol. It has an intermediate duration and has a maximum dose of 5 mg/kg without epinephrine and 7 mg/kg with epinephrine. A 1% or 2% concentration of lidocaine is injected for blocks of the nerves of the airway, typically in a volume of 1-2 ml for each site. Topical lidocaine can be administered in pledgets soaked with a 4% solution in small volumes of 1-3 ml. In addition, 2% lidocaine can be nebulized to provide topical anesthesia to the lower airways.
2. Tetracaine—this ester local anesthetic has the advantage of having a longer duration due to its very slow metabolism. Unfortunately, it also has a very slow onset, is extremely toxic, and has a maximum safe dose of 100 mg. It can be used both topically and in a nebulized form.
3. Benzocaine—this ester local anesthetic has an extremely rapid onset and short duration of action. Its maximum dose is 100 mg mainly due to the fact that at higher doses it causes methemoglobinemia. At low concentrations, methemoglobin is harmless; but at higher concentrations, patients can become symptomatic and develop dyspnea, tachypnea, and cyanosis that would need to be treated with methylene blue.

It should be noted that these local anesthetics are often used in combination to optimize the pharmacodynamics of both drugs. Hurricane spray is a combination of benzocaine and tetracaine, whereas Cetacaine spray is a combination of benzocaine, tetracaine, butyl aminobenzoate, benzalkonium chloride, and cetyldimethylethylammonium bromide.

NEUROANATOMY AND REGIONAL BLOCKS

In order to adequately perform nerve blocks of the upper airway, one should have a good understanding of the neuroanatomy of the upper airway. The main nerves that have to be blocked are the trigeminal nerve, glossopharyngeal nerve, and the vagus nerve. These blocks are further described and illustrated in chapter 23.

Trigeminal Nerve (Cranial Nerve V)

The three main nerves from the trigeminal nerve that have to be blocked are the anterior ethmoid nerve and the greater and lesser palatine nerves.

Anterior Ethmoid Nerve

A branch of the ophthalmic division of the trigeminal nerve, it innervates the nares and the anterior third of the nasal septum (Fig. 8-1). This nerve can be easily blocked by placing a cotton swab along the dorsal surface of the nose until the cribriform plate is reached. It is a valuable block to perform when doing a nasal intubation.

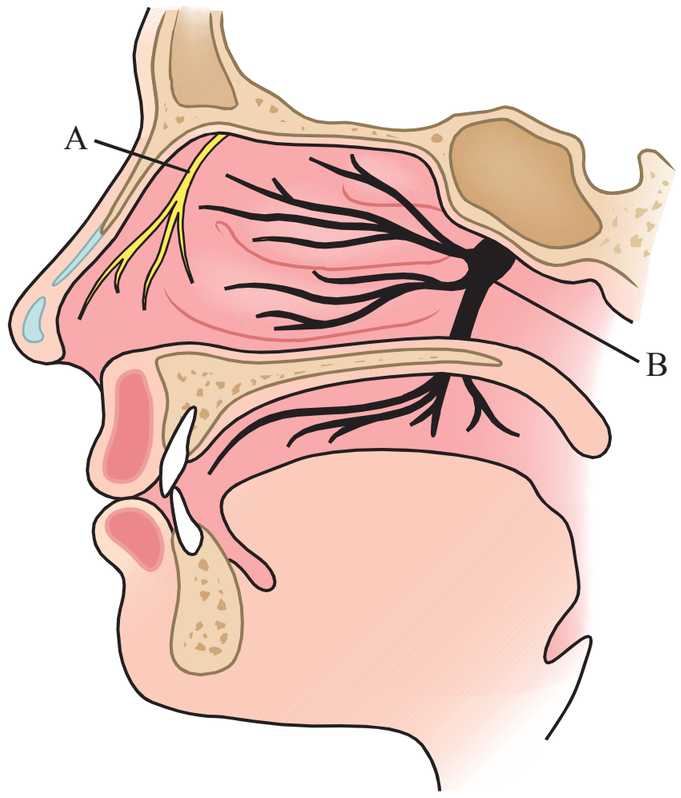


FIGURE 8-1 Neuroanatomy of the nasopharynx. **A** is the anterior ethmoid nerve. **B** is the sphenopalatine ganglion with the greater and lesser palatine nerves.

Greater and Lesser Palatine Nerves

These nerves come off the sphenopalatine ganglion, which itself comes off the maxillary division of the trigeminal nerve (Fig. 8-1). These nerves innervate the rest of the nasal mucosa as well as the nasopharynx. There are two main approaches to blocking these groups of nerves.

1. The noninvasive approach involves passing cotton swabs soaked in local anesthetic along the upper border of the middle turbinate until the posterior wall of the nasopharynx is reached (Fig. 8-2).
2. The invasive (oral) approach involves locating the greater palatine foramen that is located in the posterior lateral aspect of the hard palate about 1 cm medial to the second and third molars. A spinal needle is then inserted in a superior/posterior direction at a depth of 2 to 3 cm.

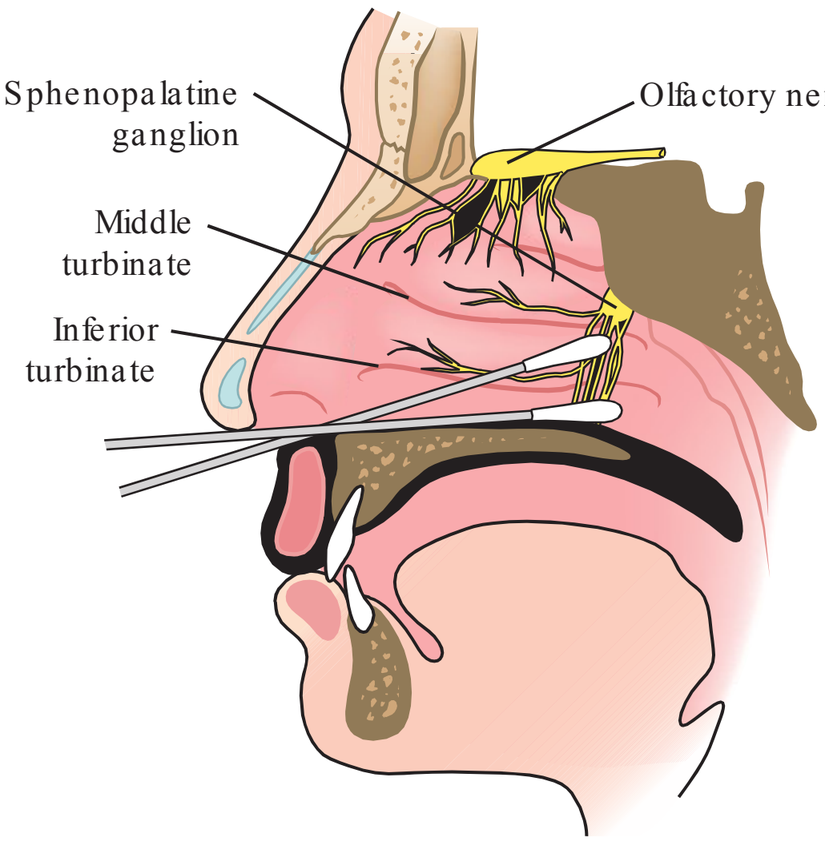


FIGURE 8-2 Schematic of the noninvasive approach to do a sphenopalatine nerve block.

Glossopharyngeal Nerve (Cranial Nerve IX)

The glossopharyngeal nerve is the main sensory nerve of the oropharynx. From its origin in the medulla, the glossopharyngeal nerve leaves the skull through the jugular foramen and travels with the internal carotid and jugular vein for a time until it starts to travel anteriorly along the lateral surface of the pharynx in the palatoglossal arch (Fig. 8-3). There it splits into three branches. The lingual branch innervates the vallecula, anterior surface of the epiglottis, and posterior third of the tongue. The walls of the pharynx are innervated by the pharyngeal branch, and the tonsils are innervated by the tonsillar branch.

There are several approaches that have been used to block the glossopharyngeal nerve. The noninvasive approach involves taking cotton balls soaked with local anesthetic and placing them in the inferior-most portion of the soft-tissue fold that makes up the palatoglossal arch.

If this approach proves inadequate, then a more invasive approach can be performed. In this approach, a 22G or smaller needle is inserted in the inferior aspect of the palatoglossal arch (Fig. 8-4). An aspiration test is done in

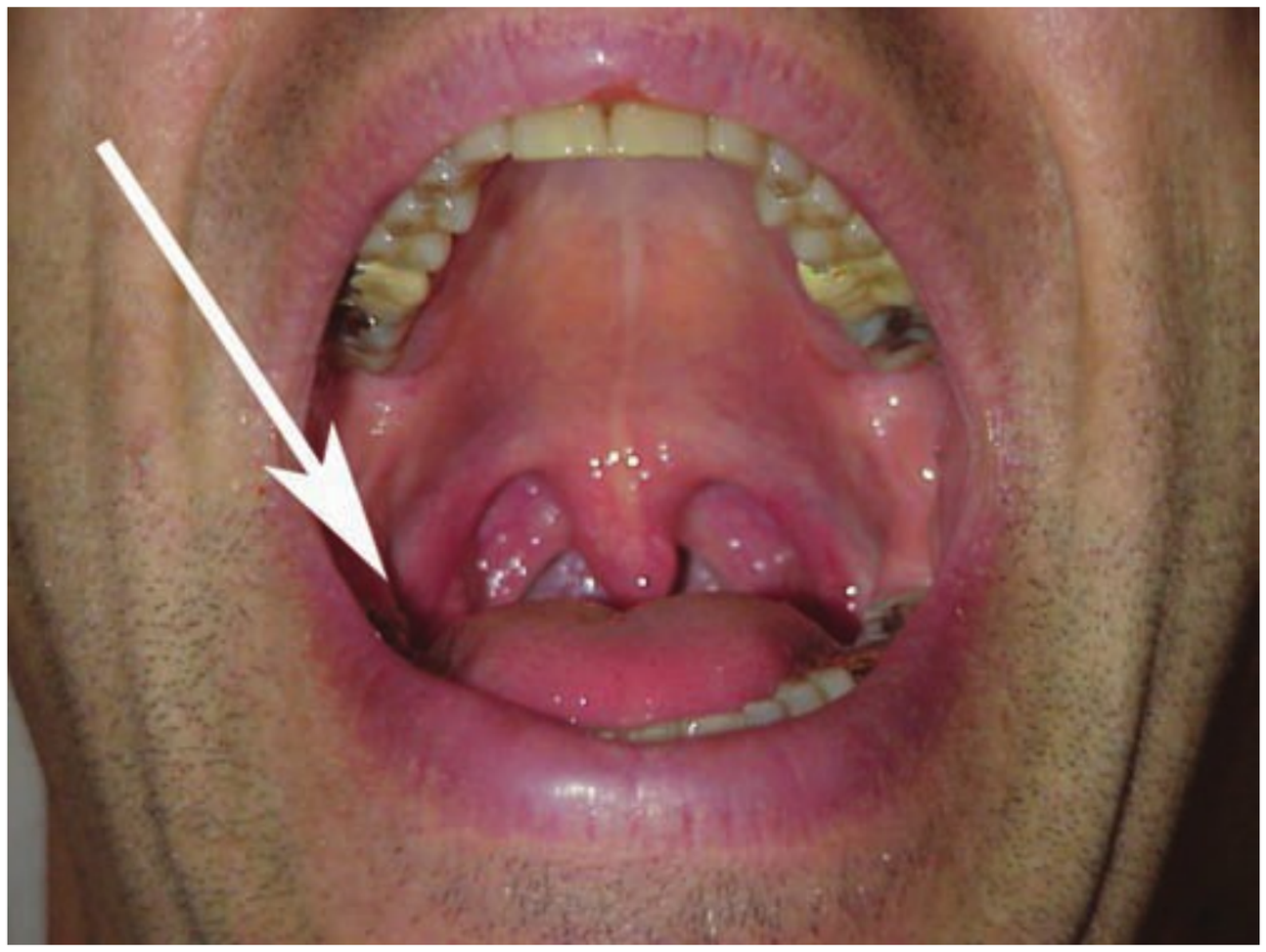


FIGURE 8-3 The arrow points to the palatoglossal arch, the glossopharyngeal nerve lies at the base of this structure. In this area, the glossopharyngeal nerve is easy to block with both invasive and noninvasive approaches.

(Reused with permission from Rosenblatt WH, Sukhupragarn W. Airway management. In: Barash PG, Cullen BF, Stoelting RK, et al, eds. Clinical Anesthesia. 6thed. Philadelphia, PA: Lippincott Williams & Wilkins; 2009: 775.)



FIGURE 8-4 The invasive intraoral approach to a glossopharyngeal nerve block.

(Reused with permission from www.nysora.com/peripheral_nerve_blocks/head_and_neck_block/3049-regional-topical-anesthesia-endotracheal-intubation.html)

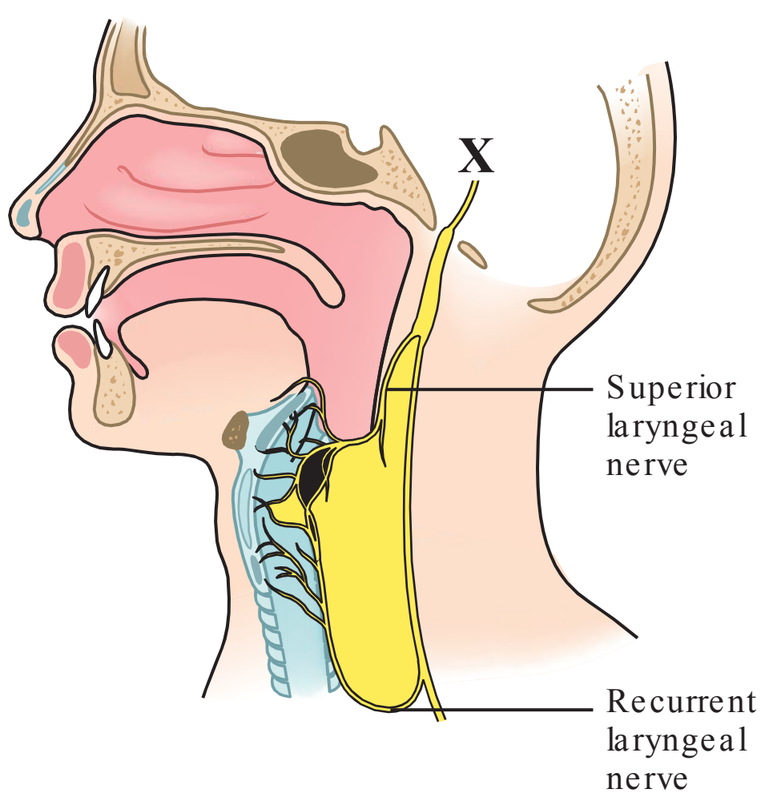


FIGURE 8-5 The innervations of the larynx by the vagus nerve. The first branch coming off is the superior laryngeal nerve and the second branch coming off is the recurrent laryngeal nerve.

order to make sure no blood is seen as the carotid artery is in close proximity to the glossopharyngeal nerve.

Vagus Nerve

The vagus nerve is the major parasympathetic nerve and hence innervates many organs in the body. The upper airway is innervated by two major branches of the vagus nerve, the superior laryngeal nerve and the recurrent laryngeal nerve (Fig. 8-5).





FIGURE 8-6 Superior laryngeal nerve block and relevant anatomy.

(Reused with permission from Hagberg CA. Airway blocks. In: Chelly JE, ed. Peripheral Nerve Blocks: A Color Atlas. 2nded. Philadelphia, PA: Lippincott Williams & Wilkins; 2009: 181–182.)

Superior Laryngeal Nerve

The superior laryngeal nerve is made up of two components, the internal and external branch. The internal division provides sensory innervation to the base of the tongue, epiglottis, supraglottic mucosa, thyroepiglottic joint, and cricothyroid joint. The internal division has no motor innervations. The external division provides sensory innervations to the anterior subglottic mucosa as well as motor innervations to the cricothyroid muscle.

Anatomically, the superior laryngeal nerves lie between the greater cornu of the hyoid bone and superior cornu of the thyroid cartilage. The internal branch of the superior laryngeal nerve pierces the thyrohyoid membrane, whereas the external branch remains superficial to the membrane.

The invasive superior laryngeal nerve block involves identifying either the superior cornu of the thyroid cartilage or the greater cornu of the hyoid bone. The best way

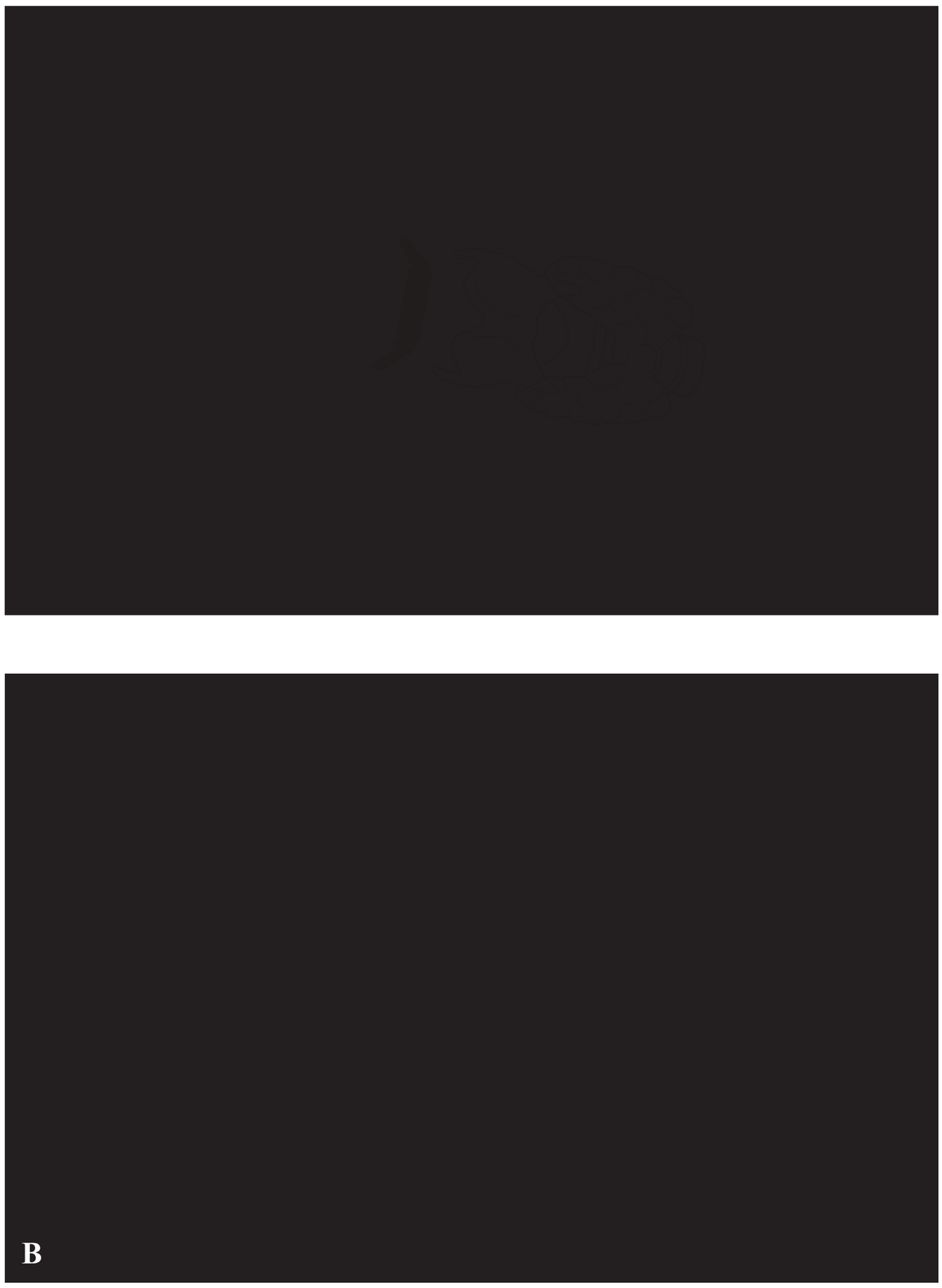


FIGURE 8-7 Transtracheal nerve block of the recurrent laryngeal nerve and relevant anatomy. (Reused with permission from Hagberg CA. Airway blocks. In: Chelly JE, ed. Peripheral Nerve Blocks: A Color Atlas. 2nded. Philadelphia, PA: Lippincott Williams & Wilkins; 2009:183–184.)

to demonstrate this is to apply pressure to the other side of the larynx, so that these boney and cartilage landmarks become more prominant. Then with a 22G or smaller needle, the operator walks inferiorly off the greater cornu of the hyoid bone or walks superiorly off the superior cornu of the thyroid cartilage until the thyrohyoid membrane is pierced (Fig. 8-6). Care must be taken to make sure that blood is not aspirated back from the needle as the carotid artery is in close vicinity. If air is aspirated, then the needle is too deep and may have penetrated the trachea.

The noninvasive oral approach involves grasping the tongue with a piece of gauze and then with Krause forceps placing a piece of lidocaine soaked gauze over the lateral tongue and then eventually in the piriform sinuses bilaterally.

Recurrent Laryngeal Nerve

The recurrent laryngeal nerve provides sensory innervations to the subglottic mucosa and muscle spindles and provides a motor innervation to the thyroarytenoid, lateral cricoarytenoid, interarytenoids, and posterior cricoarytenoids.

The main way to block the recurrent laryngeal nerve is by a transtracheal approach. In this approach, the thyroid cartilage is identified superiorly in the neck, and the cricoid cartilage is identified inferiorly in the neck. In between these two cartilages lies the cricothyroid membrane. Using a 22G or smaller needle, one can pierce this membrane until air is aspirated. At that time, local anesthetic can be injected (Fig. 8-7). The needle should be aimed inferiorly to avoid vocal cord injury.

It is also possible to anesthetize the recurrent laryngeal nerves by directly spraying local anesthetic solution through a fiberoptic bronchoscope as it is inserted into the airway during an awake intubation procedure.

CONCLUSIONS

The upper airway is an extremely sensitive area that is innervated by several different nerves. As a result, there is no one nerve block that will completely topicalize the airway. However, if one appreciates the anatomy of the upper airway and takes a holistic approach to awake intubation, including proper counseling, premedication, and nerve blocks, then the actual intubation will be comfortable, painless, and safe for the patient.

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PART II

Difficult Airway Management: Recognition, Training and Management

CHAPTER 9

Definition, Incidence, and Predictors of the Difficult Airway

Arun L. Jayaraman and Paul E. Biegeleisen

The term "difficult airway" defies simple characterization as there is no published standard definition. It may be interpreted to indicate challenging or impossible mask ventilation (IMV), glottic visualization, and/or endotracheal tube placement. Regardless, prudence dictates careful study of these aspects of airway management. This is particularly true when considering that examination of the American Society of Anesthesiologists closed claims project indicates that a significant proportion of adverse anesthetic outcomes were associated with respiratory events, including inadequate ventilation, difficult tracheal intubation, and esophageal intubation, accounting for significant morbidity and mortality.[1] Of note, many of these events were deemed to be preventable. Similar observations were made in a retrospective analysis of over 80,000 anesthetics.[2] As such, the subsequent text contains a discussion of the definition, incidence, and predictors of difficult mask ventilation (DMV) and difficult intubation (DI) in adults.

DIFFICULT MASK VENTILATION

DMV has been defined using various criteria, including poor oxygenation as detected via pulse-oximetry, inadequate chest excursion, a leak around the mask, and necessity of two-handed mask ventilation. Previously, the American Society of Anesthesiologists Practice Guidelines for Management of the Difficult Airway defined DMV as the inability of an unassisted anesthesiologist to either maintain an $SpO_2 > 90\%$ using 100% oxygen and positive pressure mask ventilation (in a patient whose SpO_2 was greater than 90% prior to induction of anesthesia) or to prevent or reverse signs of inadequate ventilation during positive pressure mask ventilation.[3] The updated guidelines provide a broader definition of DMV as the inability of an anesthesiologist to provide adequate mask ventilation due to poor mask seal, excessive gas leak, and/or significant impedance to gas entry or exit.[4,5] Furthermore, these guidelines enumerate sundry signs of ineffective mask ventilation, including inadequate chest excursion, inadequate breath sounds, auscultatory evidence of obstruction, cyanosis, gastric insufflation, inadequate SpO_2, inadequate end-tidal carbon dioxide, inadequate spirometric measures of exhaled gas flow, and hemodynamic changes associated with hypoxemia and/or hypercapnia.

Despite the importance of adequate mask ventilation in managing the difficult airway, as emphasized in the American Society of Anesthesiologist's difficult airway algorithm, research examining the incidence and predictors of DMV is somewhat sparse, particularly when compared with that regarding difficult tracheal intubation. An observational study involving 1,502 adults undergoing abdominal, gynecologic, orthopedic, urologic, and neurosurgery with general anesthesia indicates that DMV may be as common as 5%.[6] The incidence of IMV was 0.07%. This study identified several independent risk factors for DMV/IMV: age > 55 years, BMI > 26 kg/m^2, presence of a beard, lack of teeth, and history of snoring. Interestingly, reduced mouth opening and a receding mandible, two indicators of DI which will be discussed in more detail subsequently, were not associated with DMV in a statistically significant fashion. Of concern, preoperative airway assessment only predicted DMV in 17% of patients with DMV.

In another observational study involving 22,660 adults undergoing general anesthesia, the authors observed an incidence of 1.4% for DMV and 0.16% for IMV,[7] as assessed using a previously proposed numerical grading scale for mask ventilation.[8] This study identified several independent risk factors for DMV and IMV. Specifically, predictors of DMV included age ≥ 57 years, BMI ≥ 30 kg/m^2, Mallampati III or IV classification, presence of a beard, severely limited jaw protrusion, and snoring. Predictors of IMV were a history of snoring and thyromental distance (TMD) less than 6 cm. Of note, a subsequent study by the same group involving 53,041 adults undergoing general anesthesia

identified several additional independent predictors of IMV, including male sex, history of obstructive sleep apnea (OSA), history of neck irradiation, Mallampati III or IV classification, and presence of a beard.[9] Independent risk factors for difficult or impossible mask ventilation and DI were BMI≥30 kg/m^2, limited or severely limited mandibular protrusion, abnormal neck anatomy, history of snoring, and history of OSA.

Despite differences in the incidences of DMV and IMV described in published studies, ranging from 1.4% to 7.8% and 0.07% to 0.16%, respectively, which are likely attributable to varying definitions, common independent risk factors for DMV/IMV include increased age, increased BMI, presence of a beard, and snoring.[6,7,9–11] Although there is no single ideal means of prospectively screening patients for the likelihood of DMV/IMV, common sense indicates that one should consider a combination of factors that would maximize sensitivity, potentially at the expense of specificity. A reasonable set of criteria for predicting DMV/IMV may include history of DMV/IMV, abnormal neck anatomy/craniofacial abnormality, history of neck irradiation, male sex, increased age, increased BMI, history of snoring or OSA, Mallampati III or IV classification, limited jaw protrusion, lack of teeth, presence of a beard, poor atlanto-occipital extension, and pharyngeal pathology. Unfortunately, there is no robust prospectively validated screening algorithm for DMV/IMV. Having said that, one would anticipate the pretest probability of DMV/IMV increasing in proportion to the number of positive risk factors. The only readily modifiable risk factor is presence of a beard. Of interest, most published data indicate a strong correlation between difficult ventilation and intubation.[6,9,10,12] This is not surprising as many of the predictors for DMV/IMV also apply to DI, as detailed in the following text.

DIFFICULT INTUBATION

As with DMV, DI has been defined in various ways. In practice, DI frequently results from inability to obtain adequate glottic visualization with laryngoscopy. The American Society of Anesthesiologists Practice Guidelines for Management of the Difficult Airway defines difficult laryngoscopy as impossible visualization of any portion of the vocal cords following multiple attempts at conventional laryngoscopy. DI is characterized as requiring multiple attempts, whereas failed intubation is described as inability to properly place an endotracheal tube despite multiple attempts.[4]

A large prospective observational study involving 18,500 patients indicates incidences of difficult and failed intubation of 1.8% and 0.3%, respectively.[13] This study showed a positive correlation between DI and obesity, decreased TMD, limited mouth opening, reduced neck extension, male sex, and poor laryngeal exposure.[13] Overall, the incidence of difficult laryngoscopy, defined as Cormack-Lehane laryngoscopic view ≥ 3 (Fig. 9-1A–E), is 1% to 4%,whereas that of failed intubation is 0.05% to 0.35%.[14] Of note, the probability of encountering IMV and impossible endotracheal intubation in the same patient is estimated at 0.0001% to 0.02%.[14] The importance of predicting DI is underscored by a large retrospective study which found that almost half of anesthetic complications related to airway management were preventable, as they were thought to be a consequence of either failed recognition of DI or inappropriate choice of intubating technique.[2]

History of Difficult Intubation

History of DI is likely the most reliable predictor of future DI.[15,16] Among the various prognostic factors for DI, history of DI is of particular value as it aids the clinician in managing the airway of a patient in whom intubation may not be predicted to be problematic by other measures. As such, the practice at our institution is to document DI in such a fashion that it is prominently displayed in the electronic medical record along with pertinent details and future recommendations; patients are also given a letter to show those that cannot access the electronic record. Of course, although a history of DI does not necessarily indicate future difficulty, prudence dictates a cautious and determinate approach to airway management in these patients. The corollary to this is that airway management may not remain facile in a given patient although it was previously documented as such.

Mallampati Classification

Including modifications, Mallampati scoring is the most widely used and studied preoperative airway examination tool, so much so that it is a standard component of the preoperative evaluation. Mallampati classification provides a qualitative estimate of tongue size relative to the oropharyngeal cavity, as the tongue must be displaced into the floor of the mouth in order to visualize the larynx during direct laryngoscopy. The Mallampati score is determined by the ability to visualize the uvula, faucial pillars, and/or soft palate.[17,18] The original classification scheme comprised three categories of oropharyngeal classification that were found to correlate with glottic exposure during direct laryngoscopy in a statistically significant fashion: Mallampati I indicates visualization of the uvula, faucial pillars, and soft palate; in the Mallampati II classification the uvula is masked by the base of the tongue but the faucial pillars and soft palate remain visible; and Mallampati III denotes visualization of the soft palate only. Samsoon and Young[19] subsequently modified the Mallampati scoring system, adding Mallampati IV, which refers to visualization of the hard palate only, as their retrospective analysis of 13 failed intubations linked the Mallampati IV classification to failed intubation. This modified Mallampati score (MMS) is depicted in Fig. 9-2A–E.



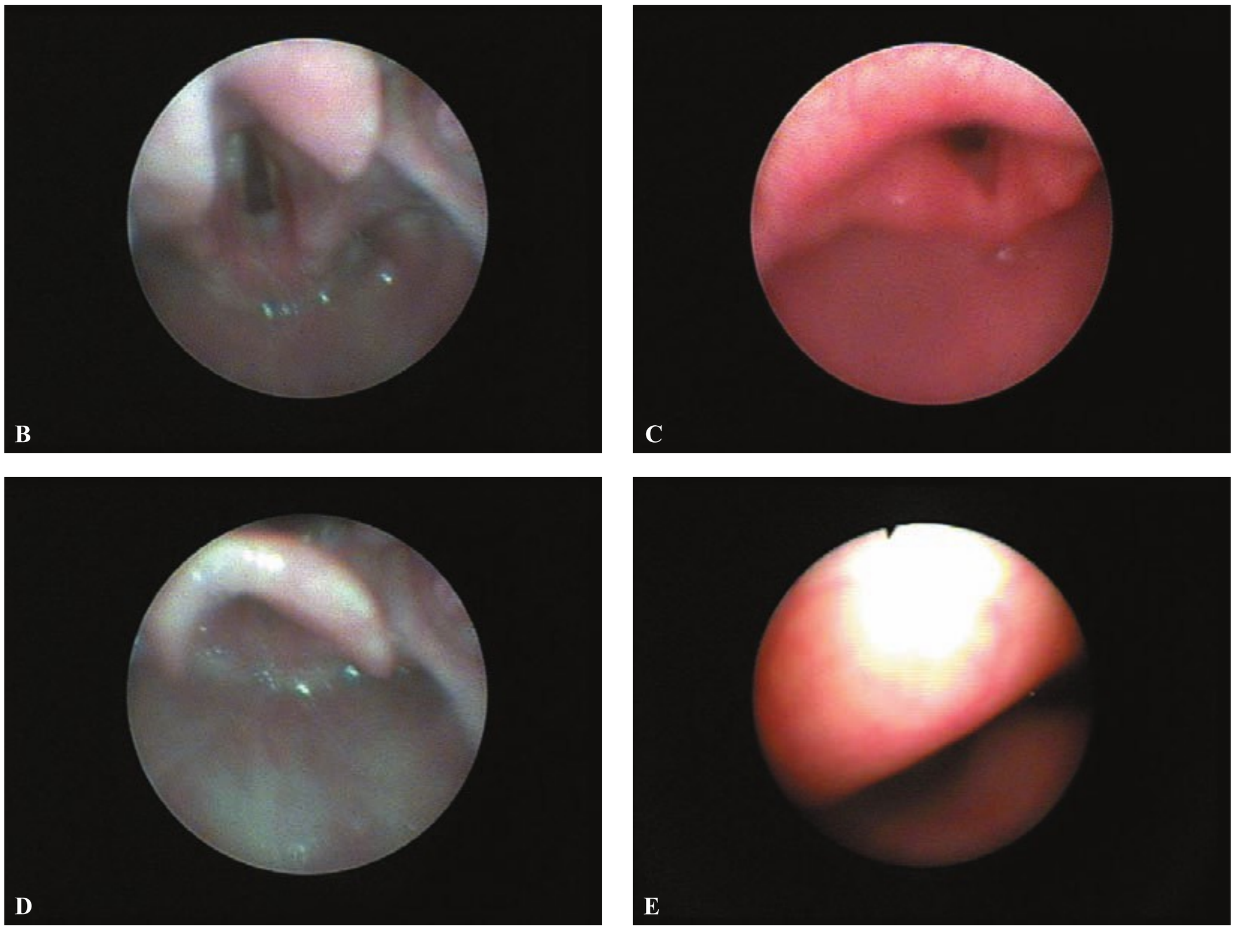


FIGURE 9-1 Cormack-Lehane grading of glottic exposure with direct laryngoscopy. **A:** Grades of laryngeal exposure. (From Samsoon GL, Young JR. Difficult tracheal intubation: a retrospective study. *Anesthesia*. 1987;42:487–490 with permission.) **B–E:** Photographs of the various Cormack-Lehane grades, appear in order of increasing score — **B:** Grade 1 laryngeal exposure; **C:** Grade 2 laryngeal exposure; **D:** Grade 3 laryngeal exposure; **E:** Grade 4 laryngeal exposure.

Of note, as originally described, the Mallampati classification was assessed with the patient sitting upright and tongue maximally extended; head positioning and phonation were not specified.[18] In developing the MMS, Samsoon and Young[19] used the sitting position with the head neutral and tongue extended; phonation was not specified. A subsequent prospective analysis investigating the effects of patient positioning on oropharyngeal classification, which was in turn correlated with ease of direct laryngoscopy using the Cormack-Lehane system, indicates that ideal assessment occurs with the patient sitting with head extended, tongue maximally protruded, and phonation.[20] Subsequent comparisons of this extended Mallampati score (EMS) with MMS suggest that EMS is associated with 7% to 10% increased specificity, up to 83%, for difficult laryngoscopy and comparable sensitivity.[21,22] Interestingly, there is some data indicating that MMS grade is increased by changing from the sitting to supine position.[23] Furthermore, MMS assessment done in the supine position may be associated with

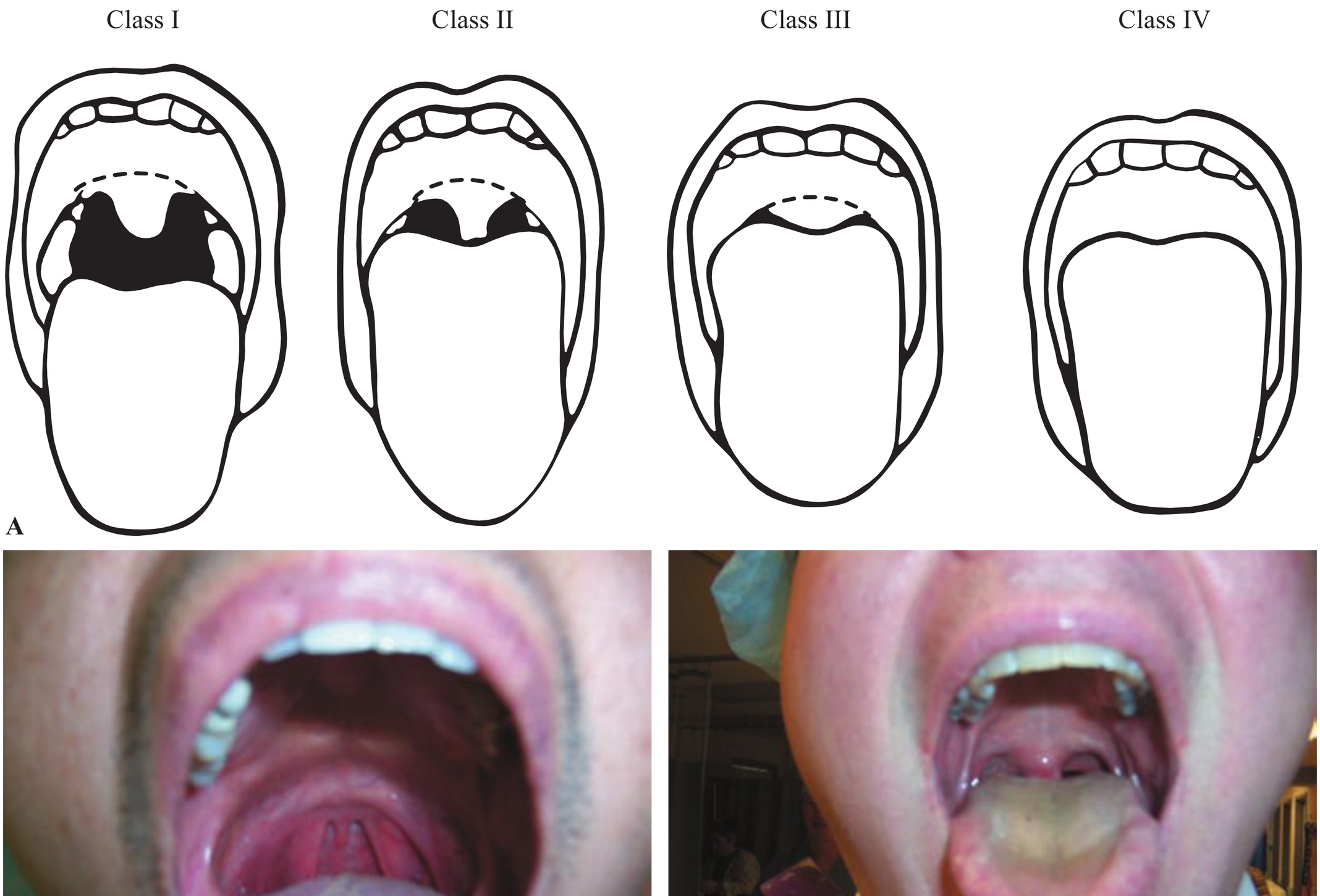


FIGURE 9-2 Modified Mallampati scoring. **A:** A depiction of the Samsoon and Young modification of Mallampati oropharyngeal assessment.

(From Jackson C. The technique of insertion of intratracheal insufflation tubes. *Surg Gynecol Obstet*. 1913;17:507–509 with permission; From Magill IW. Technique in endotracheal anesthesia. *Br Med J*. 1930;2:817–819 with permission.) **B–E:** Photographs of the various modified Mallampati classes, appear in order of increasing score — **B:** class 1 view of the oropharynx; **C:** class 2 view of oropharynx; **D:** class 3 view of oropharynx; **E:** class 4 view of oropharynx.



FIGURE 9-3 Depiction of normal cervical range of motion. **A:** Neutral position. **B:** Full extension at the atlanto-occipital joint should be 35°.

increased positive predictive value for difficult laryngoscopy compared with that done in the sitting position.[24,25] Fig. 9-2 contains photographs of the four classes in the modified Mallampati scheme and four grades of glottis exposure of the Cormack-Lehane system.

Cervical Spine Range of Motion

The importance of craniocervical extension in facilitating endotracheal intubation via direct laryngoscopy has been described as early as 1913 (Fig. 9-3A, B).[26] The utility of atlanto-occipital extension and cervical flexion (the "sniffing" position) results from aiding in alignment of the oral, pharyngeal, and laryngeal axes.[27] Moreover, craniocervical extension also facilitates intubation by enhancing mouth opening.[28] In order to properly assess cervical range of motion (CROM), one must examine both flexion of the lower cervical spine and extension of the atlanto-occipital joint, as seen in Fig. 9-3. Numerous studies have verified the role of limited cervical spine mobility, often defined as CROM < 80° to 90°, in predicting DI with direct laryngoscopy.[22,29–31] Retrospective examination of over 1,000 intubations in patients with limited cervical spine mobility indicates that age ≥ 48 years, MMPIII or IV status, and TMD < 6 cm are independent predictors of DI in this patient population.[22]

These considerations are also relevant to airway management of patients with unstable cervical spines, including trauma patients who require emergent intubation. In these patients, the standard approach is to carefully remove the cervical collar and maintain manual inline stabilization (MILS) of the cervical spine. This is done as cervical collars have been shown to reduce laryngeal exposure secondary to decreased inter-incisor distance (IID), resulting in a more posterior view of the glottic aperture.[32] Unsurprisingly, there is also data indicating that laryngeal exposure is reduced with MILS.[33,34] Specifically, in one study of over 150 subjects comparing laryngoscopic view with and without MILS in the same individuals, the authors found that, with MILS, laryngeal exposure was reduced in 45% of participants and that only the epiglottis was visible in 22% of subjects.[33] These findings only further complicate airway management of a patient who one may not have had the opportunity to adequately assess prior to induction/airway instrumentation.

Inter-incisor Distance

IID, which is a measure of mouth opening, incisor prominence, and temperomandibular joint mobility, indicates ease of laryngoscopy as it assesses the space available for insertion and manipulation of the laryngoscope and endotracheal tube (Fig. 9-4).An adequate IID is considered to be 3 to 5 cm or 2 to 3 fingerbreadths between the central maxillary and mandibular incisors with maximal mouth opening, as shown in Fig. 9-4. Reduced IID may be due to decreased temperomandibular joint mobility or prominent incisors. Prominent maxillary incisors may impede laryngoscopy by resulting in a more posterior view of the larynx. Additionally, poor dentition requires added care to avoid dental trauma, potentially involving manipulation of the laryngoscope into less than optimal positions.

Thyromental Distance

The TMD is the length between the thyroid cartilage and the mentum, or chin, as measured with the patient's head in maximal atlanto-occipital extension, as depicted in Fig. 9-5. Some data indicate that it may be better to measure from the inner rather than the outer mentum, perhaps due to variability in subcutaneous fat on the bony prominence of the chin.[35] TMD measurement provides insight into the mandibular space length available for displacement of the tongue into during laryngoscopy. A TMD of less than 6 cm (width of three middlemost fingers) is a risk factor for DI, although this has been challenged by



FIGURE 9-4 Assessing inter-incisor distance. Normal range of motion of the temporomandibular joint should permit insertion of three fingers aligned vertically into the mouth.



FIGURE 9-5 Assessment of thyromental distance, from the mentum of the mandible to the superior margin of the thyroid cartilage, should exceed 6 cm or 3 fingerbreadths.

some.[36] Of note, a very long TMD may predispose to DI due to a more caudally displaced larynx, resulting in more of the tongue being present in the hypopharynx, in turn rendering laryngoscopy more challenging.[36–38] Several studies indicate that TMD has high specificity but poor sensitivity in predicting DI.[39,40]

Obesity

Numerous, but not all, studies indicate a link between obesity and increased likelihood of difficult airway management. This is commonly attributed to an enlarged tongue and redundant soft tissue. Also, obese patients will decompensate/desaturate sooner following apnea than their nonobese counterparts. As discussed previously, there is significant data correlating obesity with difficult ventilation; in these studies, obesity was defined as a BMI greater than either 26 or 30 kg/m^2.[6,7,9] There are similar data regarding obesity and DI. Of note, there are two specific questions to consider: comparing the incidence of DI in lean versus obese patients and determining whether, among obese patients, increased BMI serves as an independent predictor of DI.

A study of over 1,800 patients found that obesity, defined as a BMI > 30 kg/m^2, results in an almost three-fold increase in the incidence of difficult laryngoscopy.[41] Similarly, a meta analysis of 35 studies indicates more than a three-fold increase in DI in obese versus lean patients.[42] Another investigation reported that the incidence of DI, as assessed using the intubation difficult scale (IDS),[43] is 2.2% in lean patients (BMI < 30 kg/m^2) and 15.5% in obese patients (BMI ≥ 35 kg/m^2).[44] This study also concludes that, of the examined characteristics (age, sex, BMI, snoring, OSA, diabetes, mouth opening < 3.5 cm, neck movement < 80°, missing teeth, buck teeth, receding mandible, and MMS III-IV), only MMS III-IV is a statistically significant risk factor for DI in obese patients, and even this showed relatively poor sensitivity, specificity, and negative predictive value.[44] A subsequent study showed a similar increase in likelihood of DI, as assessed using the IDS, of 3% versus 14.5% in lean (BMI < 30 kg/m^2) and obese (BMI ≥ 30 kg/m^2) patients, respectively.[45] Apart from increased BMI, other statistically significant risk factors for DI identified in this study include MMS≥3 and neck circumference > 43 cm, as measured at the level of the thyroid cartilage; interestingly, in this study, increased neck circumference is also a predictor of DI in lean patients. Another report examining morbidly obese patients (BMI > 40 kg/m^2) linked MMS ≥ 3 and increased neck circumference at the level of the thyroid cartilage, but not increased BMI, with DI in this patient population.[46] In contrast, an analysis of morbidly obese patients (mean BMI 49.4 kg/m^2) undergoing bariatric surgery found a significant correlation between DI and male gender as well as MMS ≥ 3 but not increased BMI, increased neck circumference, or history of OSA; increased neck circumference was associated with difficult laryngoscopy but not DI.[47] Of note, although obesity renders mask ventilation more problematic, some maintain that, with proper planning and positioning (ie, a "ramp"), obesity alone does not predispose to DI.[48,49]

Upper Lip Bite Test

Although the upper lip bite test (ULBT) is a relatively new assay, the notion that receding and/or poorly mobile mandibles hinder laryngoscopy is not a novel one.[50] The ULBT was initially proposed as a possible replacement for MMS in predicting difficult laryngoscopy.[51] ULBT serves as an indicator of the roles of mandibular mobility,

or lack thereof, and dental architecture in impeding laryngoscopy. There are three ULBT classes: in class I, the mandibular incisors can bite the upper lip above the vermilion line; in class II, the mandibular incisors can bite the upper lip below the vermilion line; and in class III, the mandibular incisors cannot bite the upper lip.[51] Although not nearly as thoroughly evaluated as MS/MMS, some but not all data indicates that the ULBT assay may be more specific than MMS in predicting DI with comparable sensitivity.[51,52] As compared with other tests, specific advantages of this assay include ease of use and interobserver reliability.[52] Interestingly, there is some data indicating that ULBT may also serve as a predictor of difficult ventilation.[53] Furthermore, ULBT may be a more sensitive predictor of DI using the Glidescope video laryngoscope than MMS.[54]

Airway Management Outside of the Operating Room

There are significant difficulties encountered in emergent airway management that are not encountered in the elective, preoperative setting. As noted previously, obtaining a history and physical examination may be impossible when the patient is obtunded or severely dyspneic, and time is of the essence. Furthermore, the very nature of the emergency may lead to increased difficulty in ventilation and laryngoscopy. The presumption of a "full stomach" in all patients intubated emergently dictates use of the rapid sequence intubation (RSI) technique. The imposition of cricoid pressure and of laryngoscopy at the earliest possible moment after administration of hypnotics and muscle relaxants may increase the physician's stress level and distort the view of the larynx.[55] The trauma patient places even more obstacles in the path of the intubating physician: facial distortion, secretions, swelling, mandibular injury, and potential cervical spine injury all combine to make these patients among the most challenging airway management problems.[56] As discussed previously, cervical collars and in-line immobilization impact glottic exposure adversely, and up to 20% of these patients may have a grade 3 or grade 4 laryngoscopic view.[33] In fact, a recent observational study of over 3,000 emergent nonoperative intubations found an incidence of DI of 10.3% and that of complications related to intubation of 4.2%, higher than typically seen in the operating room.[57] Independent predictors of complications included general floor and emergency department (ED)but not intensive care unit locations.

The incidence of DAM in the ED population has not been studied as thoroughly as that in the operating room. Sakles et al report intubation of 610 patients in an urban ED over a 1-year period, 84% of whom were managed with the RSI technique and 16% of whom were deemed unfit for RSI. The overall success rate of these intubations was 99%, with esophageal intubation occurring in 5% of patients, with rapid correction, and 5% of patients requiring three or more attempts at direct laryngoscopy. Also, 1% of patients required an emergent surgical airway. Overall, the range of DI in this study appears to be between 5% and 27%, depending on the extent of overlap.[58]

In the investigation of Tayal et al, the proportion of patients whom the investigators were unable to manage with direct laryngoscopy was similarly low, with only 1% requiring a surgical airway. However, 30% of patients who were intubated were not included in the analysis because they did not meet the investigators' requirements for eligibility for RSI. Thus, the actual incidence of DI lies somewhere between the extremes of 1% and 31%.[59]Even if the lower range is chosen, DI in the ED is not rare and seems to be more common than in the population presenting for elective surgery. In a multicenter study of ED airway management in more than 6,300 cases, the incidence of esophageal intubation was found to be 4%, and the failure rate for intubation when RSI was used to secure the airway was less than 2%.[60,61]

SPECIAL CIRCUMSTANCES

Please note that there are certain conditions, not discussed in the preceding text, that further predispose to DMV/DI. These include acute infections (ie, croup, epiglottitis, and retropharyngeal/tonsillar abscesses), ankylosing spondylitis, burns, certain congenital disorders/syndromes (ie, acromegaly, choanal atresia, Downs syndrome, mucopolysaccharidoses, PierreRobin sequence, TreacherCollins syndrome, etc.), diabetes mellitus, pregnancy, rheumatoid arthritis, tumors of the upper airway, and upper airway trauma. This is not intended to be an exhaustive list, and some of these conditions will be discussed further elsewhere in this text.

SUMMARY

There are certain circumstances, such as gross craniocervical pathology, which render airway assessment easy. These are situations where one aspect of the examination is so telling that it renders the remainder of the assessment almost irrelevant. Such cases are relatively infrequent. In most patients, one applies a series of tests, the subjective sum of which form the basis of the airway assessment. As expected, there are data showing that sensitivity and specificity is increased by considering several parameters, typically including history of DI, MMS/EMS, CROM, TMD, IID, dentition, BMI, and/or ULBT. Unfortunately, efforts to prospectively validate an airway assessment tool using such assays have not yielded a single gold standard rubric. Thus, airway assessment often becomes an interplay between physical examination and clinical experience.

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CHAPTER

10

Computerized Analysis to Associate Facial Features with Difficult Intubation

Christopher W. Connor and Scott Segal

All patients undergoing preoperative evaluation are assessed for anatomic features that might predict difficulty in performing endotracheal intubation under general anesthesia. Typically, at least two examinations are used: the "Mallampati Test" (MP)[1,2] is performed and the thyromental distance (TMD)[3] is measured. The MP test involves an examination of oropharyngeal structures that are visible when the seated patient maximally opens the mouth and extends the tongue without phonation. The TMD measures the space between the superior tip of the thyroid cartilage and the inside of the tip of the mandible. Both tests perform only modestly, with sensitivity of 30% to 60%, specificity of 60% to 80%, and positive predictive value of just 5% to 20%.[4] Even so, the combination of MP and TMD performed better than any other bedside screening test in a meta-analysis of 35 trials studying over 50,000 subjects.[4] In practice, anesthesiologists likely weigh other subjective factors in anticipating a difficult airway, including habitus, facial appearance, and perhaps other poorly understood hunches.

Use of a bedside examination to predict difficult intubation is considered the standard of care in modern anesthesiology practice. It has been incorporated into the difficult airway algorithm of not only the American Society of Anesthesiologists (ASA)[5] and those of several other countries[6] but also most recently into the World Health Organization Surgical Safety Checklist.[7] Unfortunately, all easily performed examination systems in clinical practice perform only modestly, with sensitivities of 20% to 62%, specificities of 82% to 97%, and very low positive predictive values, generally less than 30%, unless very liberal definitions of difficulty are used.[8] There are likely several reasons for this poor performance, including the relative rarity of difficult intubation,[8] the multifactorial etiology and varying definition of difficult intubation, interobserver variability in test results,[9,10] failure to validate potential systems in patients independent of those used to derive the test,[8] and the inadequacy of the tests themselves. Conversely, experienced anesthetists almost certainly use cues other than those derived from formal bedside tests to formulate their clinical impression of the ease of intubating any given patient. There may be several anatomic factors that enter into such a judgment.[11] The development of a tool that is able to capture this gestalt of the experienced anesthesiologist remains an important, incompletely solved problem.

Suzuki et al[12] used digital photographs of subjects' faces to calculate five ratios and angles from measurements derived from placement of anatomic markers on the photographs. They found one, the "submandibular angle," to be correlated with difficult tracheal intubation. Similarly, Naguib et al[13] measured 22 indices from plain radiographs and 8 from three-dimensional computed tomography scans of the head in patients who were easy or difficult to intubate. They constructed a model containing three bedside tests (MP, TMD, and thyrosternal distance) and two radiographic features that accurately separated the easy and difficult cohorts with an AUC of the receiver operating characteristic (ROC) curve of 0.97. Both of these previous investigations, however, used a priori assumptions of which anatomic features might relate to difficult laryngoscopy and intubation. Both also required actual measurement of anatomic features.

In contrast, we have proposed a photographic technique that models the entire physiognomy of the face with no such assumptions and no direct measurements.[14] Computer software is used to reconstruct a three-dimensional model of the patient's head from three photographs, as shown in Fig. 10-1. The relative sizes of the patient's facial features can be measured from this model. Using photographs of patients whose ease or difficulty is already known, a statistical decision-making model can be derived that can distinguish those patients who are easy to intubate from those who are difficult. This statistical

model does not contain any a priori assumptions about the facial features that may prognosticate difficult intubation. The statistical model should, without preconditioning, model the gestalt of the anesthesiologist once sufficient example cases are provided to it.

In our initial investigation, 80 Caucasian male patients were recruited postoperatively. These patients were defined as easy to intubate if their anesthetic record described a single attempt with a Macintosh 3 blade resulting in a grade 1 laryngoscopic view (full exposure of the vocal cords).[1,15] Difficult intubation was defined by at least one of the following: more than one attempt by an operator with at least 1 year of anesthesia experience, grade 3 or 4 laryngoscopic view on a 4-point scale,[15] need for a second operator, or nonelective use of an alternative airway device such as a bougie, fiberoptic bronchoscope, or intubating laryngeal mask airway.[5,16] Patients who were neither easy nor difficult to intubate by these criteria were not recruited.

The photographs were analyzed by facial structure analysis software (FaceGen Modeller v3.3, Singular Inversions, Toronto, Canada), and each face was resolved into 61 facial proportions (Table 10-1). Each parameter was tested for discriminatory ability by logistic regression,[17] and combinations of 11 variables with $P \leq 0.1$, plus Mallampati score and TMD, were tested exhaustively by all possible binomial quadratic logistic regression models.[18] Candidate models were cross-validated by maximizing the product of the area under the ROC[19] curves obtained in the derivation and validation cohorts.[14] The final model was found to depend on only three facial proportions plus TMD, as marked with asterisks in Table 10-1. Relative to an androgynous population normal shown in Fig. 10-2, the variations in facial appearance described by the

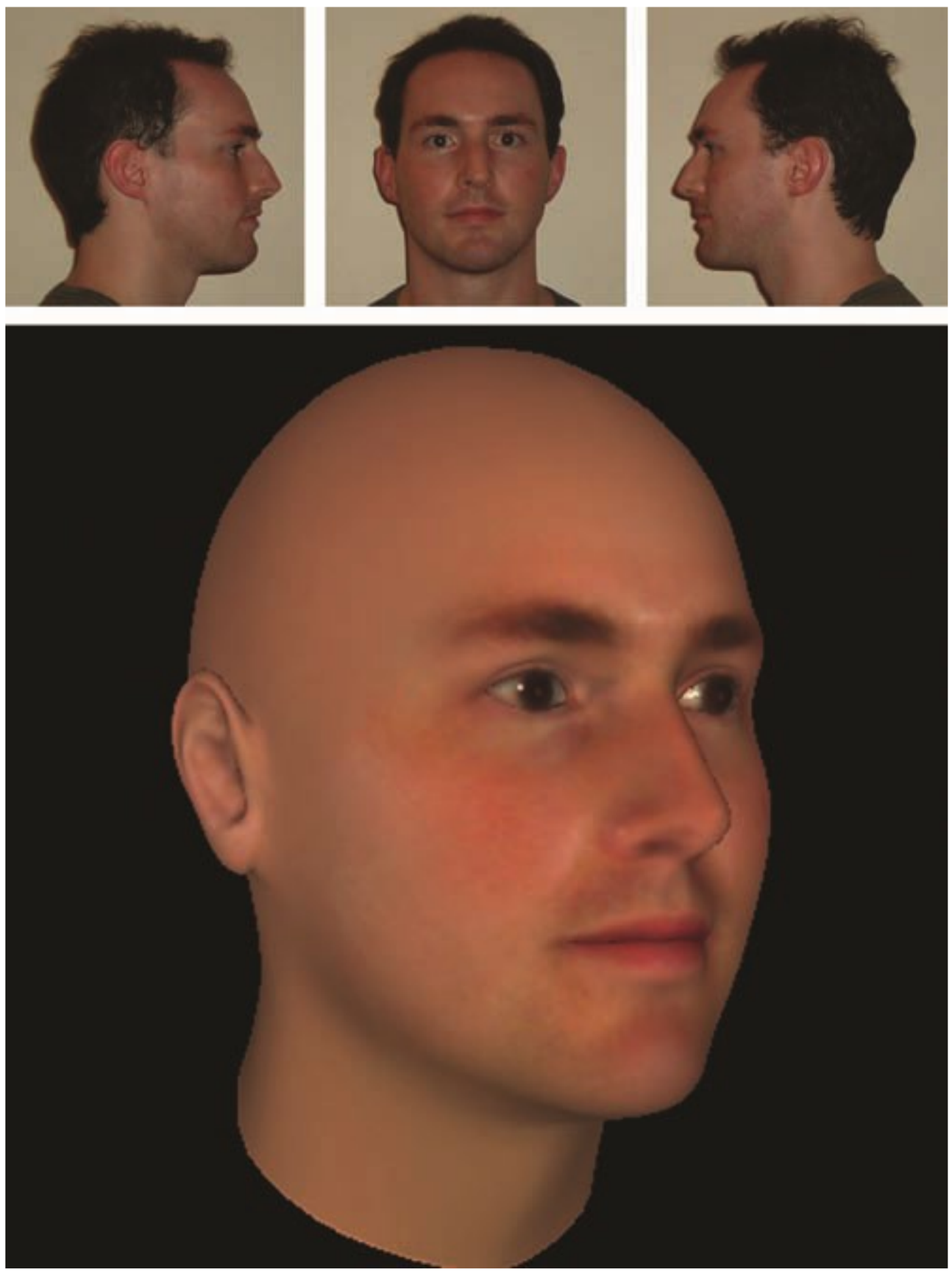


FIGURE 10-1 Computer reconstruction of the head from profile and face-on photographs (image of first author Christopher W. Connor).

Table 10-1

The 61 variables defining photographic reconstruction of the head. The TMD and MP test are included in the table as two further variables that were used for modeling. Those emphasized demonstrated at least a statistical trend ($P \leq 0.1$) with identified difficult intubation. Those marked with an asterisk appear in the final model.

Descriptive Facial Proportions

Brow ridge—high/low	Jaw—retracted/jutting
Brow ridge inner—down/up	Jaw—wide/thin
Brow ridge outer—up/down	*Jaw—neck slope high/low
Cheekbones—low/high	Jawline—concave/convex
Cheekbones—shallow/pronounced	Mouth—drawn/pursed
Cheekbones—thin/wide	Mouth—happy/sad
Cheeks—concave/convex	Mouth—lips deflated/inflated
Cheeks—round/gaunt	Mouth—lips large/small
Chin—forward/backward	Mouth—lips puckered/retracted
Chin—pronounced/recessed	Mouth—lips thin/thick
Chin—retracted/jutting	Mouth—protruding/retracted
Chin—shallow/deep	Mouth—tilt up/down
Chin—small/large	Mouth—underbite/overbite
Chin—tall/short	Mouth—up/down
Chin—wide/thin	Mouth—wide/thin
Eyes—down/up	Mouth—chin distance—short/long
Eyes—small/large	Nose—bridge shallow/deep
Eyes—tilt inward/outward	Nose—bridge short/long
Eyes—apart/together	Nose—down/up
*Face—brow-nose-chin ratio	Nose—flat/pointed
Face—forehead-sellion-nose ratio	Nose—nostril tilt down/up
Face—heavy/light	Nose—nostrils small/large
Face—round/gaunt	Nose—nostrils wide/thin
Face—tall/short	Nose—region concave/convex
Face—up/down	Nose—sellion down/up
Face—wide/thin	Nose—sellion shallow/deep[1]
Forehead—small/large	Nose—sellion shallow/deep[2]
Forehead—tall/short	Nose—sellion thin/wide
Forehead—tilt forward/back	Nose—short/long
Head—thin/wide	*Nose—tilt down/up
	Temples—thin/wide
*TMD	MP Test



FIGURE 10-2 Appearance of the average head of the reference population.

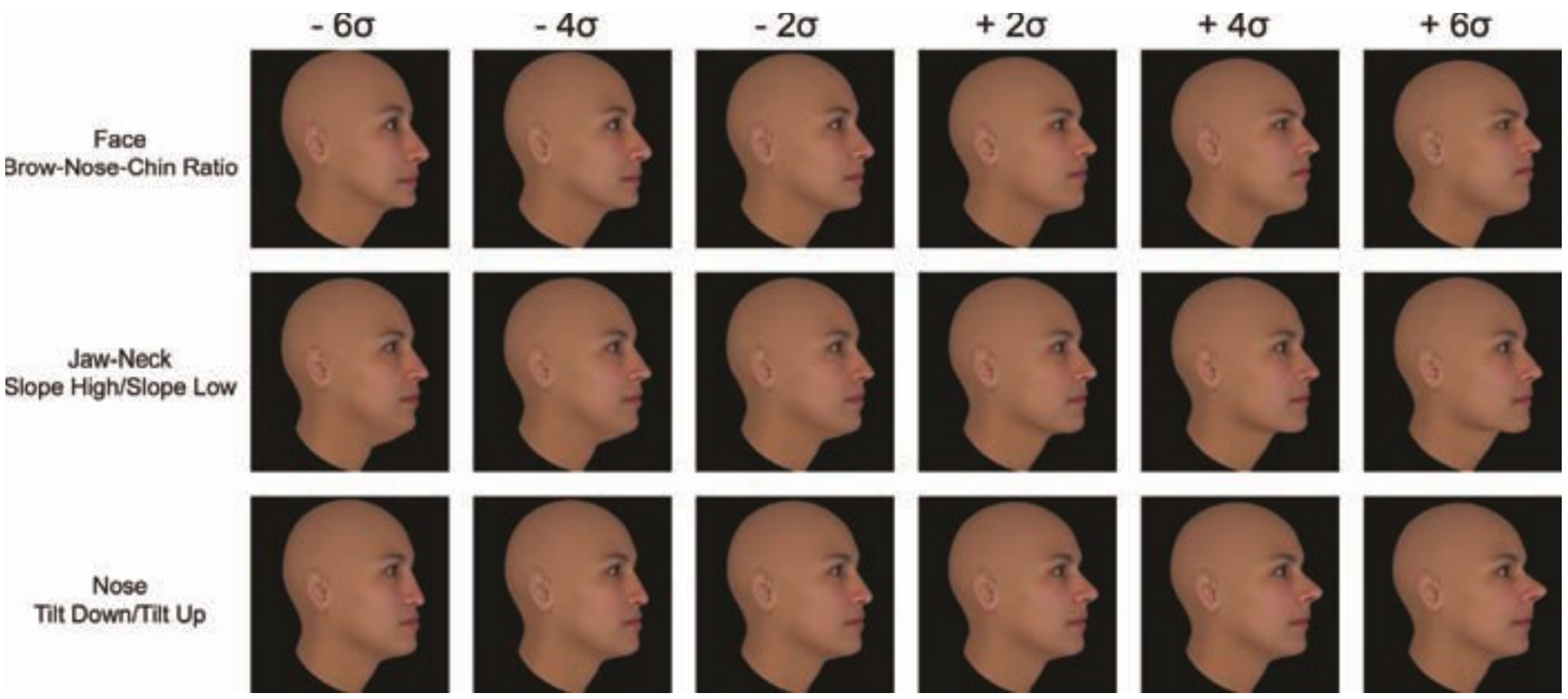


FIGURE 10-3 Variations in facial appearance from the average head shown in Figure 10-2 by standard deviations of the descriptive facial proportions used in the airway algorithm. σ is the standard deviation from the normal head derived from 300 individuals.[20]

three facial proportions used in the model are shown in Fig. 10-3.

As this airway model describes appearance, it is possible to generate pictures of faces that would appear to have certain degrees of ease or difficulty of intubation. Figure 10-4A illustrates the head that is theoretically most difficult to intubate according to the model. Figure 10-4B represents a head that the model would classify as easy to intubate. The parameter values for this head are set such that the value produced by the model is of the same magnitude but opposite to Fig. 10-4A. Figure 10-4B might therefore be considered to represent a patient as easy to intubate as the patient in Fig. 10-4A would be difficult.

There are some acknowledged limitations to this model. First, it is likely that there are causes of difficult intubation not included in the study cohorts. For example, some patients with limited neck mobility but otherwise normal airways are difficult to intubate.[21] Further refinement of the model could include subjective or measured indices of neck extension. Secondly, potentially confounding racial or gender-based factors were eliminated by confining the model to Caucasian males. Only a large, prospective study in a diverse patient population would be able to verify the effectiveness of this approach in general clinical use. In the study population characterized here, however, computerized facial structure analysis combined with a widely used bedside airway evaluation method

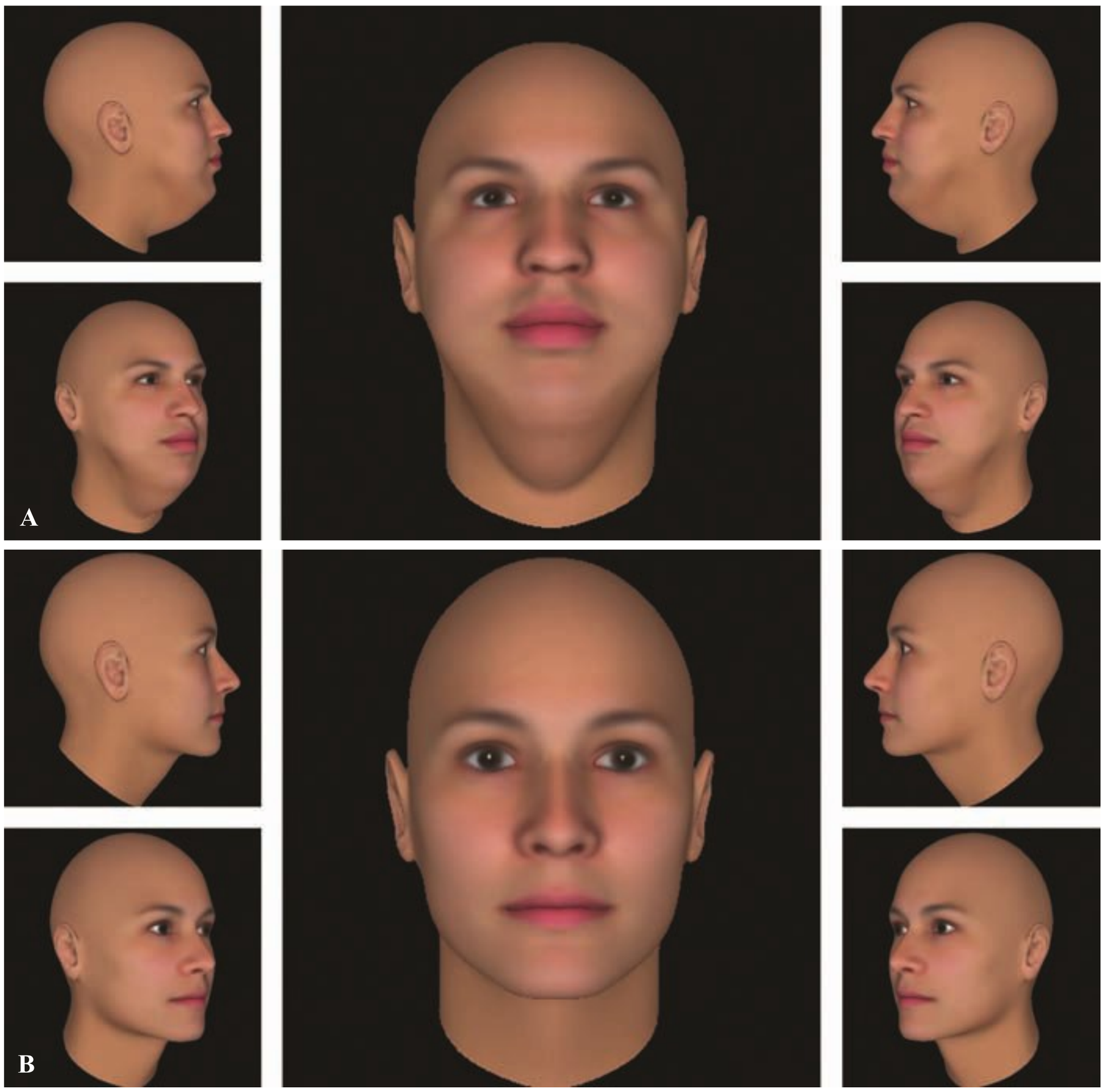


FIGURE 10-4 **A:** Appearance of the face rated most difficult to intubate by the model. **B:** Appearance of a face rated easy to intubate. The ease is comparable in magnitude to the difficulty associated with Figure 10-4A.

yielded a model that significantly outperformed popular clinical predictive tests.[1,3,14,15]

In subsequent studies, we have found that human experts (fully trained experienced anesthesiologists) cannot match the computer model when presented with similar data. Conceivably, after validating and perhaps refining the method based on a prospectively obtained, diverse sample, the method could prove useful in the practice of anesthesiology in general, as well as to airway nonexperts. We envision deploying the model over smart phones or other similar devices connected over a network to high-speed computers, evaluating the facial anatomy and applying the predictive algorithm. Future possibilities could include using similar methodology to evaluate risk of difficult mask ventilation or relative utility of various alternative airway management devices to aid the anesthesiologist in their selection in the case of a predicted difficult airway.

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CHAPTER

11

New Methods of Bedside Airway Assessment: Cone Beam Computed Tomography, Ultrasound, and Craniofacial Phenotyping

Jacek Wojtczak and Bo Hu

Most anesthesiologists predict difficult intubation based on several bedside preoperative screening tests. The most popular is establishing the degree of visibility of oropharyngeal structures based on Mallampati classification,[1] measuring thyromental distance (TMD) and assessing neck movement and mouth opening.[2–4] Unfortunately, all these tests have only modest sensitivity and specificity in predicting difficult intubation.[2–4] Baker et al[5] performed the meta-analysis of 24 studies where the accuracy of TMD measurements was assessed as predictor of difficult intubation. The test sensitivity was only 16% when fingerbreadths were used for assessment and increased to 48% when the ruler or calipers were used for measurements. It implies that the preoperative airway evaluation has to be much more quantitative in order to be predictive. In this chapter, we will review three modalities that potentially may improve preoperative airway evaluation.

MRI and CT are considered gold standards in the quantitative, three-dimensional evaluation of the airway. Both imaging techniques can perform complete volumetric airway analysis,[6–8] but MRI has an obvious advantage over CT in improved visualization of soft tissues. Both techniques are expensive, hardly bedside, not feasible in patients with metal implants (MRI), require long examination time (MRI), and expose patients to radiation (CT). Recently introduced cone beam CT, however, is becoming very popular in the office setting due to its low cost, small size, very short examination time, and very low level of patient irradiation.

Ultrasound (US) of the airway is a bedside imaging technique that has been used for several years, but the quality of US scans of the airway has been generally poor. Recent advances in this technology, availability of high-frequency probes, and inexpensive portable US units revived the interest in this modality as a convenient bedside tool.[9]

Craniofacial phenotyping is the newest of the new methods of bedside airway assessment and requires three-dimensional (3-D) laser scanning with an automated 3-D rendering[10,11] or two-dimensional (2-D) digital photography.[12]

CONE BEAM COMPUTED TOMOGRAPHY

Cone beam computed tomography (CBCT) is a recent advancement in CT imaging, facilitated by parallel advancements in flat panel detectors technology, improved computing power, and the relatively low power requirements of the X-ray tubes used.[13,14] The imaging-source detector and the method of data acquisition distinguish CBCT from traditional CT imaging. Traditional CT uses a high-output rotating anode X-ray tube, whereas CBCT uses a low-power, medical fluoroscopy tube that provides continuous imaging throughout the scan. Traditional CT records data with a fan-shaped X-ray beam onto image detectors arranged in an arc around the patient, producing a single slice image per scan. Each slice must overlap slightly in order to properly reconstruct the images. The advanced CBCT technology uses a cone-shaped X-ray beam that transmits onto a solid-state area sensor for image capture, producing the complete volume image in a single rotation. The sensor contains an image intensifier and a CCD camera, or an amorphous silicon flat panel detector.

The single-turn motion image-capture used in CBCT is quicker than the traditional spiral motion and can be accomplished at a lower radiation dose as a result of no overlap of slices. Manufacturers are designing CBCT scanners with the physical space available in clinics and patients' comfort in mind. Usually, upright seating is used in CBCT scanners with the X-ray tube and panel detector rotating around the patient's head (Figs. 11-1 and 11-2).



FIGURE 11-1 Cone beam computed tomograph (i-CAT) used for imaging of dental implants (courtesy of Eastman Dental Center, University of Rochester, NY).

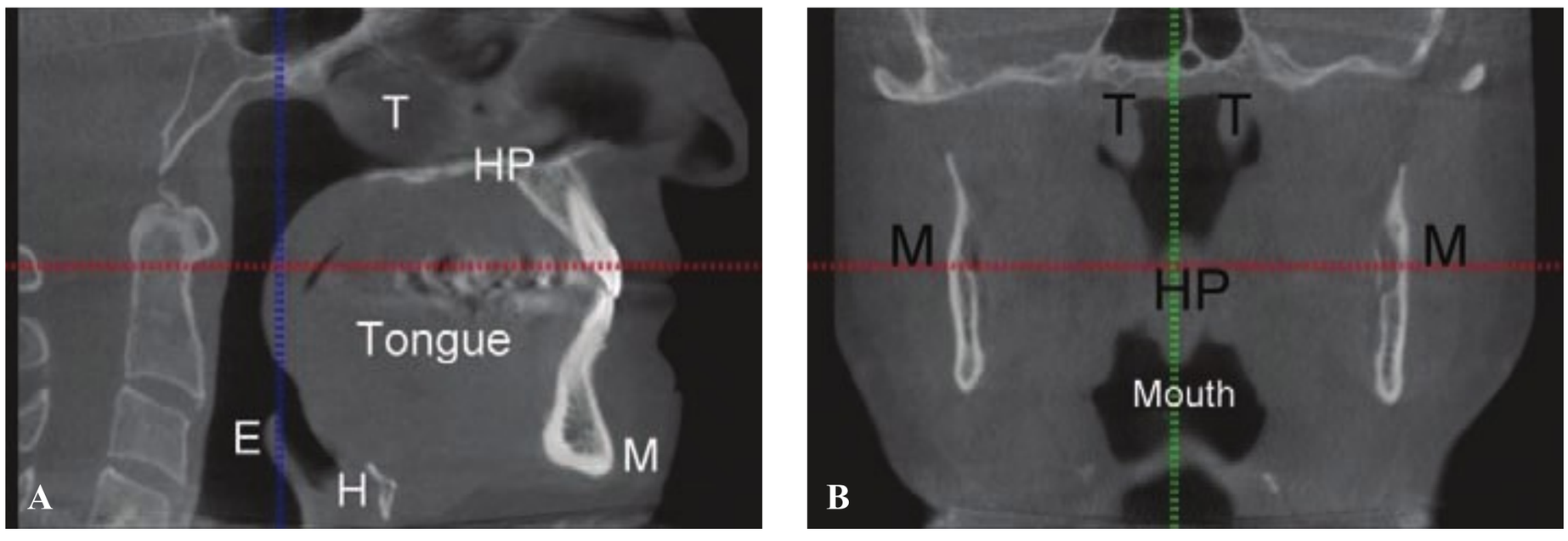


FIGURE 11-2 **(A)** Sagittal i-CAT CBCT scan: T- turbinates, HP- hard palate, H – hyoid bone, M – mandible, E – epiglottis. **(B)** Coronal i-CAT CBCT scan: T- turbinates, HP- hard palate, M – maxilla.

CBCT became a very popular modality in dentistry, especially implantology. Its value as a clinical tool is also studied in oral and maxillofacial surgery. As it provides not only skeletal but also soft tissue images with an option of 3-D reconstruction, it may become a very useful tool in upper airway examination in anesthesiology in patients known or suspected to be difficult to intubate. Osorio et al[15] published a preliminary report on the applicability of CBCT for the purpose of the clinical airway management. They performed 3-D reconstructions of the airway as well as "virtual laryngoscopy" by generating "flying through" reconstructions. They found the resulting video clips to be of high quality, similar to fiberoptic imaging, but without the invasiveness. They concluded that virtual laryngoscopy may be a promising future technique to support clinical anesthesia practice. In their opinion, CBCT has the potential to emerge as a comprehensive and practical system to evaluate the upper airway and should become an excellent research and teaching tool for understanding the normal and abnormal airway.

ULTRASOUND IMAGING

US imaging of the upper airway offers several advantages compared with other imaging techniques. It is widely available, portable, repeatable, relatively inexpensive, pain-free, and safe.[9,16–19]

The curved array low-frequency (5 MHz) transducers (Fig. 11-3) are preferred for submandibular scans to visualize the tongue and the swallowing dynamics. Patients with long hyomental distances may require a standoff to enable an accurate measurement of intraoral distances (Fig. 11-4).

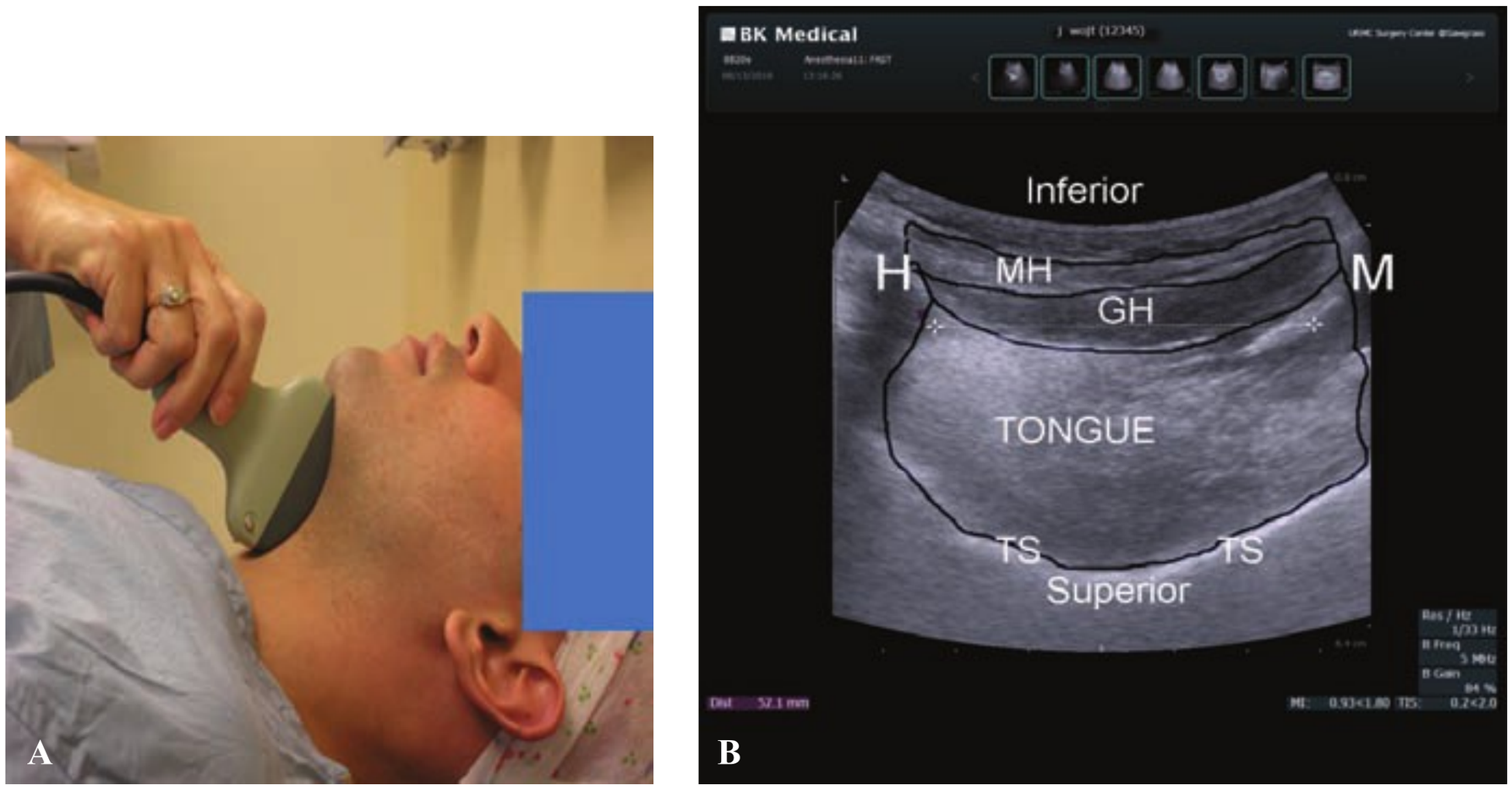


FIGURE 11-3 **A:** Midsagittal submandibular sonography using 5 MHz curved array transducer; **B:** US anatomy of the suprahyoid region. M, mandibular shadow; H, shadow of the hyoid bone; GH, geniohyoid muscle; MH, mylohyoid muscle; TS, tongue surface.

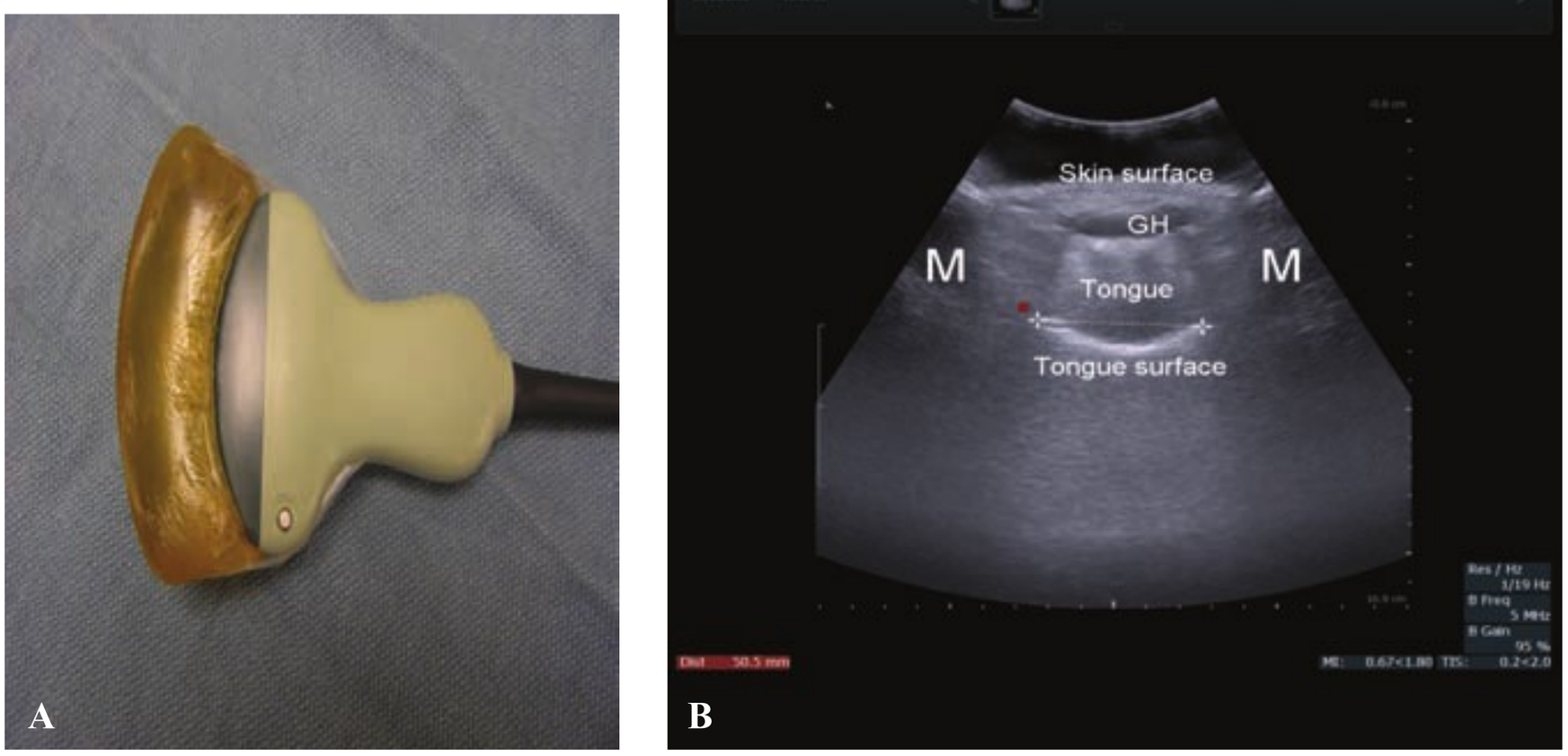


FIGURE 11-4 **(A)** Standoff gel pad attached to the curved 5 MHz ultrasound probe to enlarge the field of view and improve visualization of the near field areas (e.g. floor of the mouth). **(B)** Transverse submandibular scan with the standoff pad presenting as a hypoechoic space between the surface of the skin and the probe. M – mandible; GH – geniohyoid muscle.

The high-frequency linear probes are useful in imaging the superficial structures yielding high-resolution scans (Fig. 11-5); however, the US penetration is very poor (Fig. 11-6).

It is important to remember that US imaging is indirect and often depends on subjective interpretation. Recently, Tsui and Hui[18] described their initial experience of a novel method of US airway imaging by placing a small, high-frequency, curved array transducer in the sublingual fossa. Using this approach, they attempted to obtain a longitudinal view of the larynx by placing the probe sagittally and longitudinally under the patient's tongue. Their initial interpretation of the obtained images was incorrect and had to be retracted.[19] Initially, they described a dark anechoic structure originally interpreted as the trachea that was later confirmed to be the geniohyoid



FIGURE 11-5 Transverse scan of thyroid cartilage and the vocal cords: TC – thyroid cartilage, VL– vocal ligaments, FC – false cords. Rima epiglottidis marked with crosses.

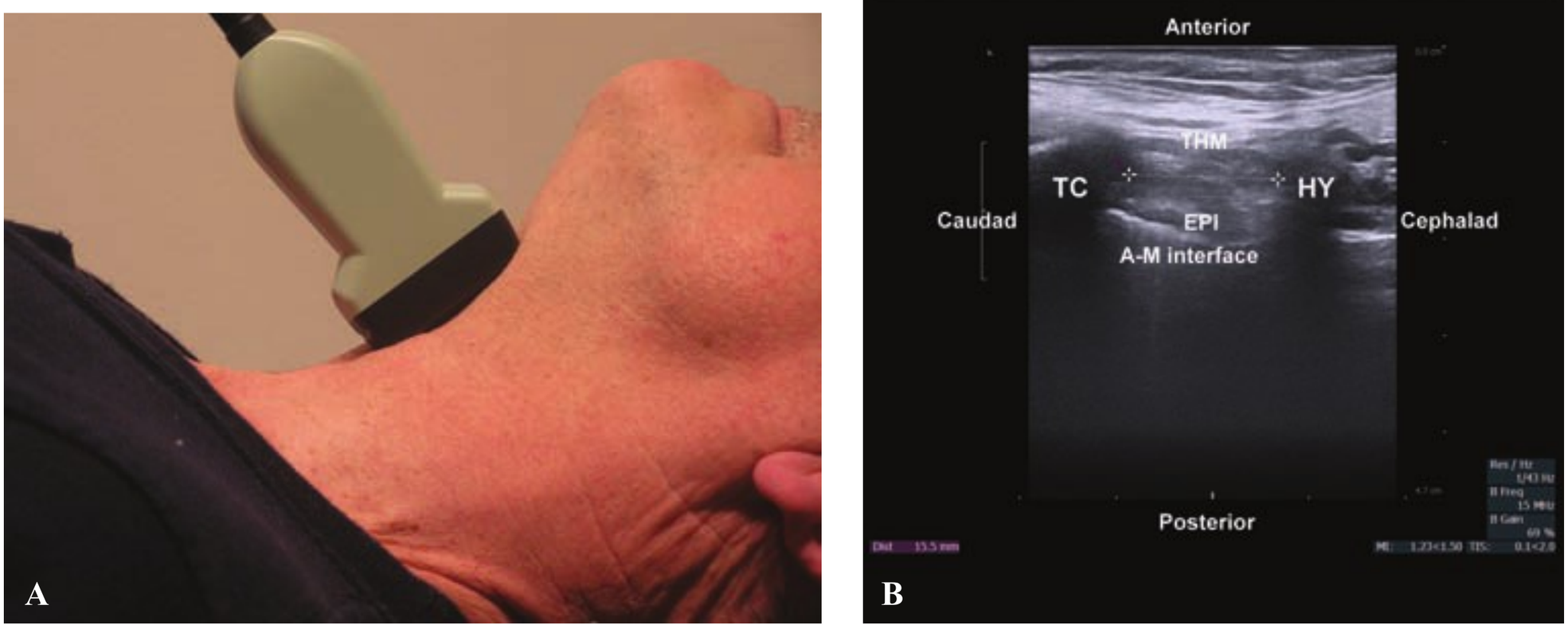


FIGURE 11-6 Sagittal scan of the thyrohyoid membrane (THM), hyoid bone (HY), thyroid cartilage (TC), epiglottis (EPI) and air-mucosa (A-M) interface. Any interface between the mucosa lining the upper airway tract and the air within it has a bright hyperechoic linear appearance [9].

muscle. The hyperechoic structure originally described by them as the epiglottis was later[19] confirmed to be the hyoid cartilage. During swallowing, a dynamic view of elevation of this distinct hyperechoic structure depicted the hyoid cartilage being pulled anteriorly by the geniohyoid muscle. Prasad et al[20] showed that the transcutaneous US using a linear, parasagittal scan could visualize the epiglottis, which we could also visualize in the midsagittal plane (Fig. 11-7).

Transverse US scanning through the cricothyroid membrane allows visualization of the vocal cords (Fig. 11-5) and their movement during respiration and swallowing. Transverse US scanning at the level of the suprasternal notch visualizes the hyperechoic thyroid gland and tracheal rings (Fig. 11-8).

US has been used to assess subglottic diameter[21] and to confirm endotracheal tube placement.[22] The echogenicity of the tube was enhanced by retaining a

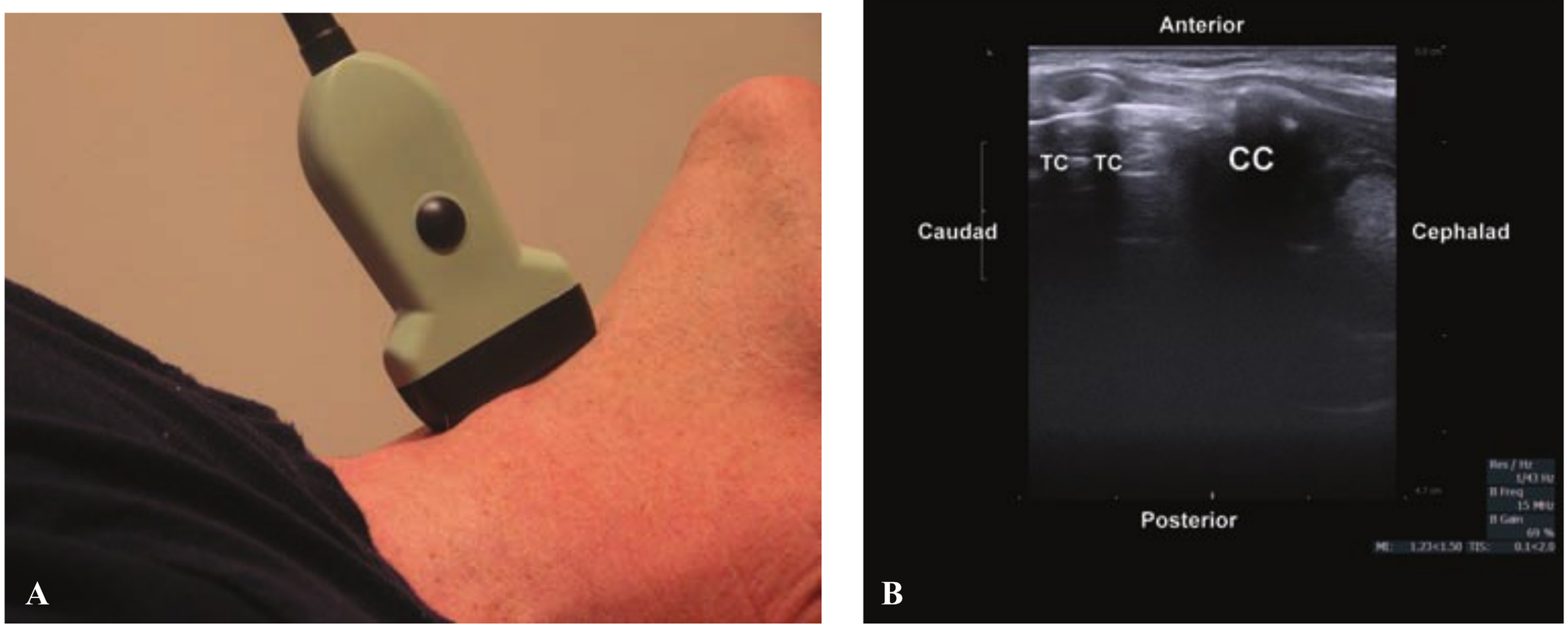


FIGURE 11-7 Sagittal scan over the trachea using a linear transducer. The sonogram shows the cricoid cartilage (CC) and the tracheal cartilages (TC).

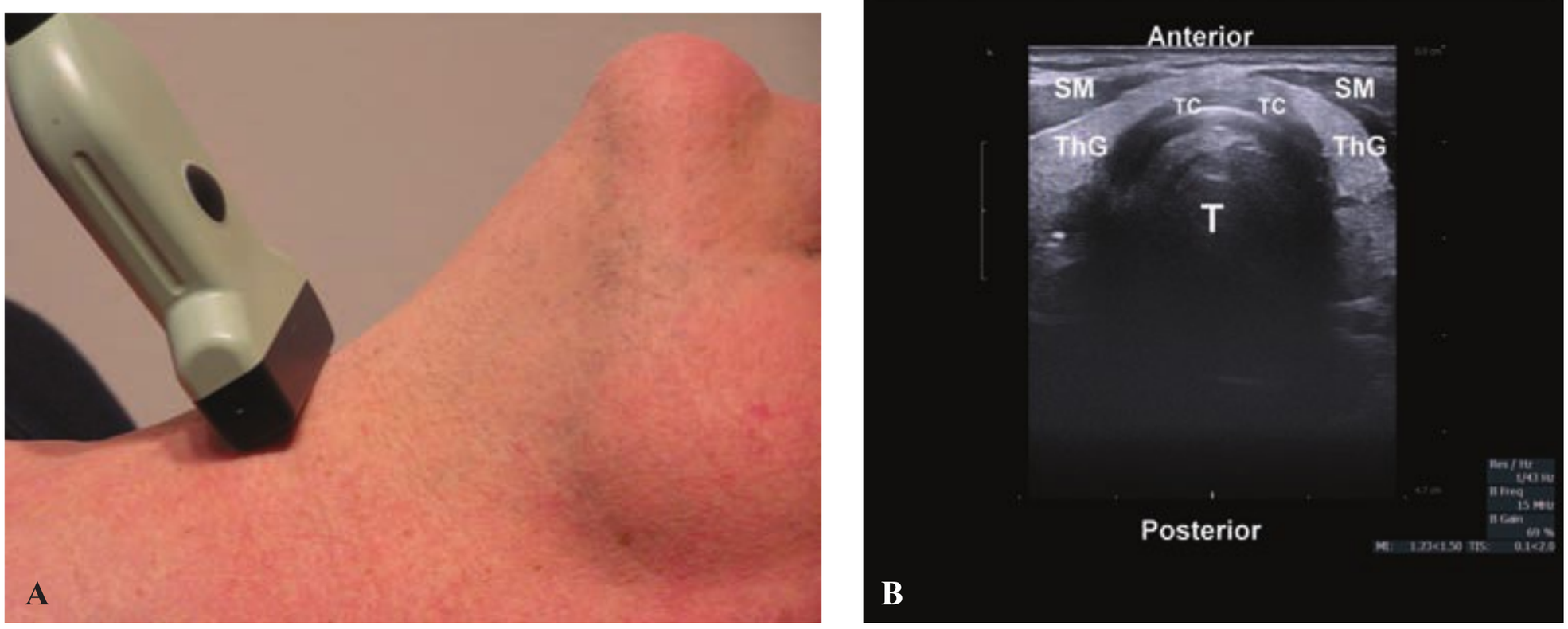


FIGURE 11-8 Transverse US scan of the thyroid gland (ThG) and tracheal cartilage (TC). T – tracheal lumen, SM – strap muscles.

stylet in the tube or by the ETT cuff with fluids and air bubbles.[16]

Sustic[16] described the US-guided percutaneous tracheostomy. The site of the puncture was usually selected between the second and third tracheal rings, after a clear US verification of the anatomy of the thyroid and cricoid cartilage and tracheal rings. The US imaging also confirmed the correct position of the tracheostomy tube after the procedure.

Sustic[16] used US imaging from the lateral neck approach to correctly position the laryngeal mask airway. The proper position of the LMA cuff, especially of its distal end could be confirmed by US when the cuff was filled with fluid.

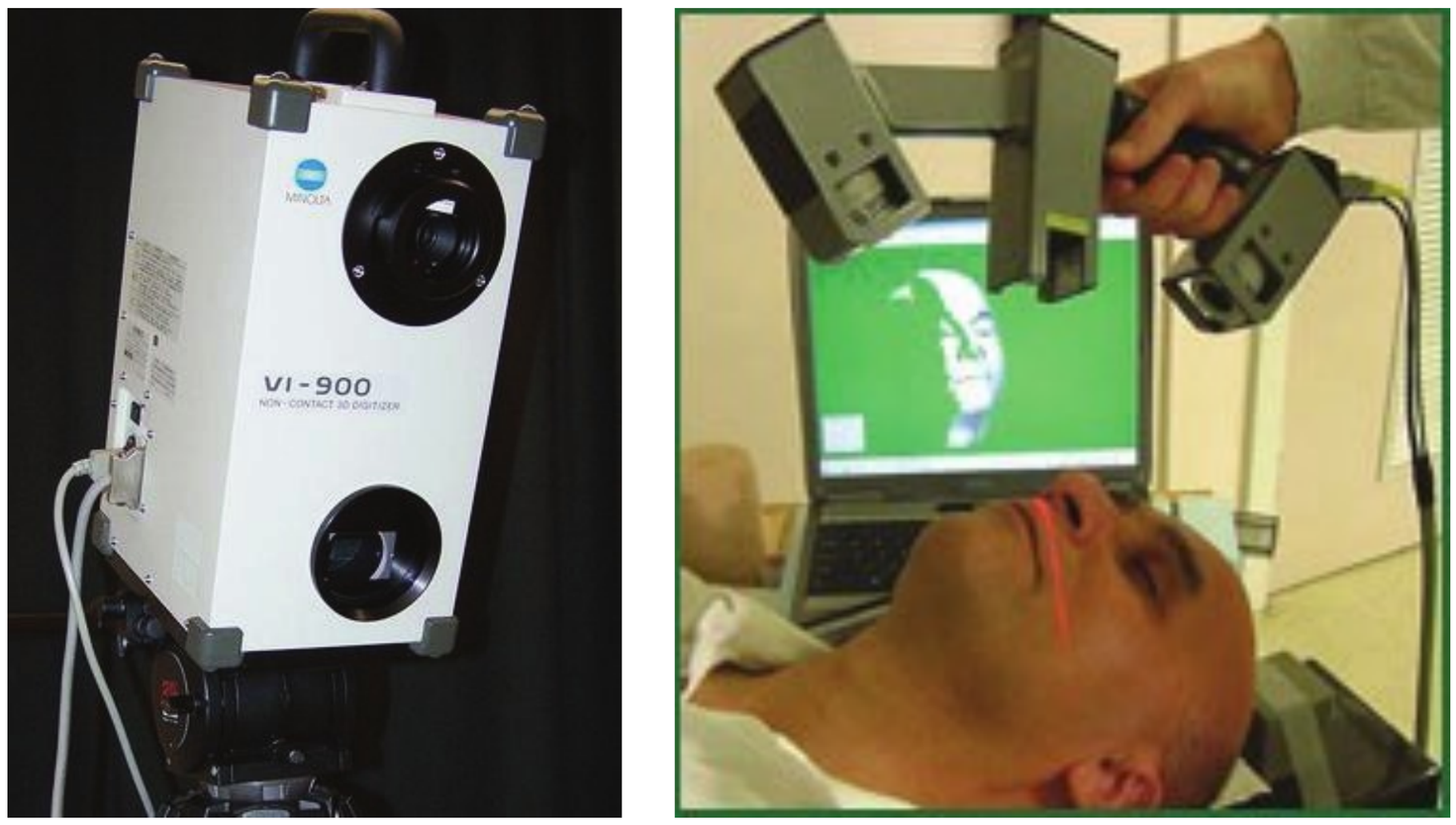


FIGURE 11-9 High-resolution Vivid 900 (Konica Minolta) laser scanner and a portable, lower resolution laser scanner with an electromagnetic positioning system (Polhemus FAST SCAN).

CRANIOFACIAL PHENOTYPING

The concept of craniofacial phenotyping is based on the assumption that certain 2-D or 3-D surface contour measurements may be identified as surrogate indicators that reflect the underlying skeletal structures or soft tissue oropharyngeal anatomy. Suzuki et al[23] performed a systematic evaluation of facial appearance of nonobese Japanese patients with a history of difficult tracheal intubation (DTI). They compared measurements obtained from the frontal and profile 2-D digital photographs with the measurements from the photographs of matched patients with easy tracheal intubation (ETI). They found that mandible position was significantly smaller in DTI males than in male patients with ETI. The submandibular angle was significantly larger in both male and female DTI patients than in patients with ETI. The *morphing* software (see below) was used to construct "average" and "exaggerated" easy and difficult to intubate faces.

A study of obstructive sleep apnea (OSA) patients showed that simple measurements from 2-D digital photographs can reveal several craniofacial differences between subjects with and without OSA.[12] The patients with OSA had wider and flatter mid and lower face, shorter jaw, and more soft tissues on the anterior neck. In a related prospective cohort study, the same group by using a model with only four photographic measurements was able to correctly classify 76% of subjects with OSA.[24] As the patients with OSA were shown to be difficult to intubate,[25] it further confirms the possibility that patients who are difficult to intubate may also have some characteristic predictive facial features.

Connor and Segal[26] showed that computerized analysis of facial structures obtained from the frontal and profile 2-D digital photographs outperformed conventional airway examination in predicting difficult intubation. Their model included three facial parameters (Jaw-Neck High/Slope Low; Nose Tilt Down/Tilt Up; Face Brow-Nose-Chin Ratio) and TMD. It correctly classified 70 of 80 subjects as DTI, whereas the combination of the Mallampati score and TMD classified only 47 of 80 subjects as DTI.

Due to the nonlinear nature of human skulls and faces, simple 2-D photographic linear measurements may result in significant errors when performed on curved surfaces such as forehead, maxilla, or mandible.[27] Moreover, 2-D photographic analysis technique may include errors from subject alignment, camera lens distortion, and projection errors.

The accuracy of measurements may be greatly improved by using noninvasive, optically based, 3-D digitization techniques. The most popular 3-D data acquisition technique that has been successfully applied to human facial measurement is laser surface scanning.[10,11] A laser beam is swept over the object while a camera mounted inside the scanner records photons reflected from the surface of an object (Fig. 11-9) and generates a set of points in 3-D space called *point cloud* and outputs a point cloud as data file. Point clouds themselves are generally not directly usable in most 3-D applications and therefore usually converted to *polygonal* mesh. Polygonal (usually triangular) mesh forms a *wire frame model* of an object. A 3-D image of an object is created from a model by a process called *rendering*.

Because of occlusion, some crucial 3-D features of the face, for example, the angle of the jaw line, cannot be obtained from a single frontal scan. Therefore, at least two extra scans have to be taken, 45° to the right and to the left of the frontal axis (Fig. 11-10). The three scans need to be stitched together to form a full 3-D face image, a process called *registration*. The Polhemus FAST SCAN but not the Vivid 900 scanner is able to stitch scans together automatically in real time due to the electromagnetic positioning system. The Vivid 900 scanner, however, has a higher resolution than the Polhemus scanner and it also records the color of each pixel, besides its depth (Fig. 11-9).



FIGURE 11-10 Merging of three laser scans to form a full 3-D face image in a process called registration. The face is not blinded because it is one of the authors (Bo Hu).

With the registered 3-D face, the anthropometric measurements can be obtained manually, for example, using commercial software, but it is tedious and error prone and not suitable for clinical use. Instead, a template 3-D face model can be employed. The shape of the model is parameterized by a large group of anthropometric features.

Landmark features, which are prominent and easily identifiable points on the face (eg, the corners of the eyes, ala nasi), are extracted on both the template face and the registered face. The template face is then morphed into the registered face by interpolating their corresponding landmark points. The morphing is represented as thin-plate spline functions, which we call the *morph function*. The anthropometric features on the patient's face are obtained automatically by applying the *morph function* on the same features defined on the template face (Fig. 11-11). These raw features form the basis of feature vector to the classification of patients.

In our recent study,[27] we have compared 3-D craniofacial laser scanning with 2-D photography (Fig. 11-12) and surface measurements as ground truth. We showed that 3-D craniofacial laser scanning is superior to 2-D photography as it captures the nonlinear nature of craniofacial anatomy. Therefore, it may be more sensitive and specific than 2-D photography in craniofacial phenotyping of patients with difficult airway and potentially useful in predicting difficult or impossible intubation. Craniofacial 2-D photographic analysis techniques allow

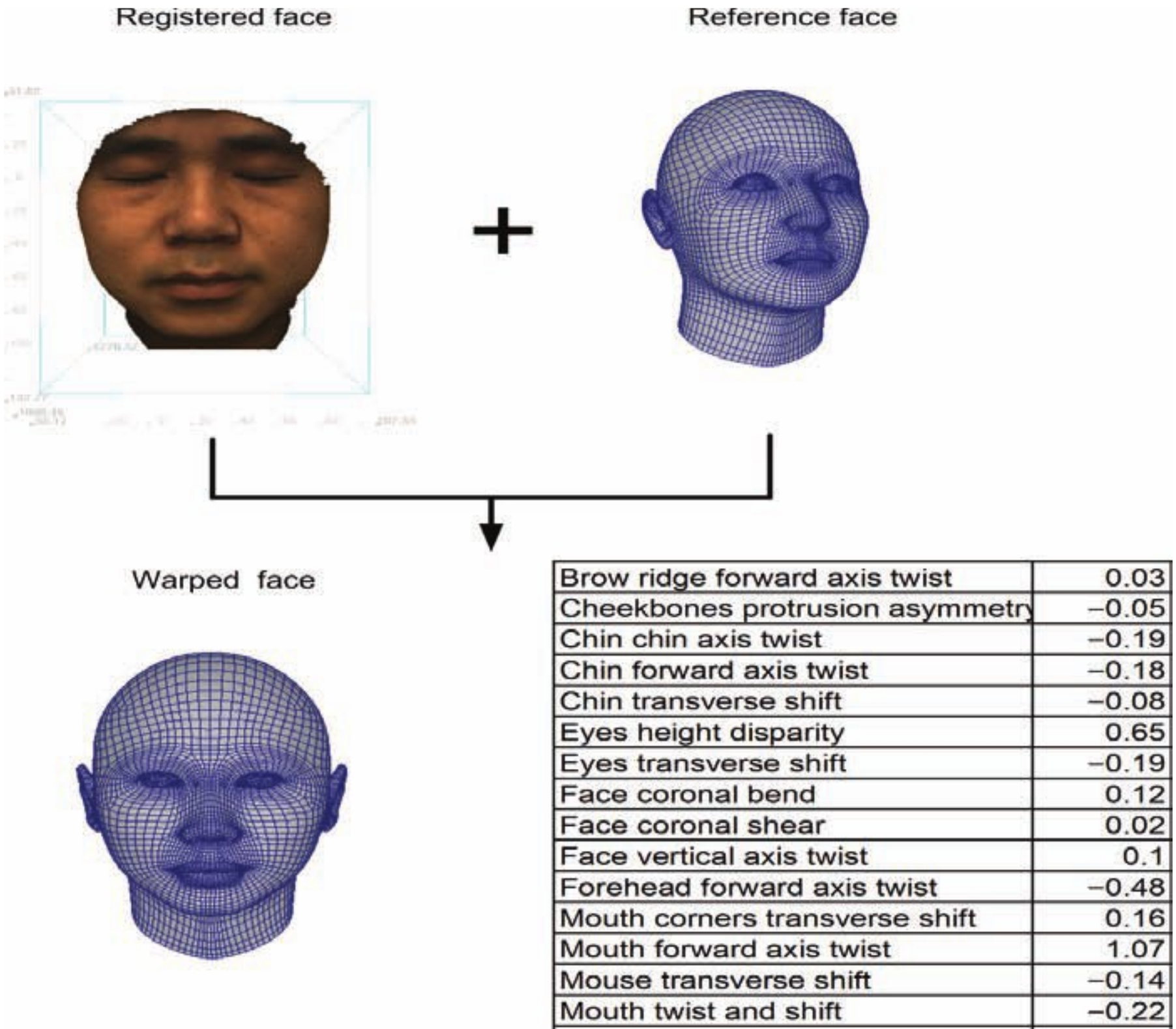


FIGURE 11-11 Computing anthropometric features. A warp function is computed from the landmarks (marked in red) matched between a registered face and the template face. The anthropometric features defined on the template face are transferred by the warp function.

Table 11-1

Surface (S) and Linear (L) Distances between Anthropometric Points of the Normal and Obese Clay Head

	Actual (S) (mm)	3-D (S) (mm)	3-D (L) (mm)	2-D (L) (mm)
Head—Normal				
T-N (L)	102.8	101.7	93.2	88.6
T-SN (L)	108.5	107.8	98.5	97.2
T-GN (L)	122.5	121.2	114.8	110.6
T-GO (L)	49.3	51.6	48.8	51.3
Head—Obese				
T-N (L)	104.3	104.1	92.5	78.8
T-SN (L)	113.1	108.3	96.2	84.1
T-GN (L)	135.2	136.5	122.9	106.7
T-GO (L)	69.3	68.7	69.3	73.8

Abbreviations: T, tragion; N, nasion; SN, subnasion; GN, gnathion; GO, gonion.

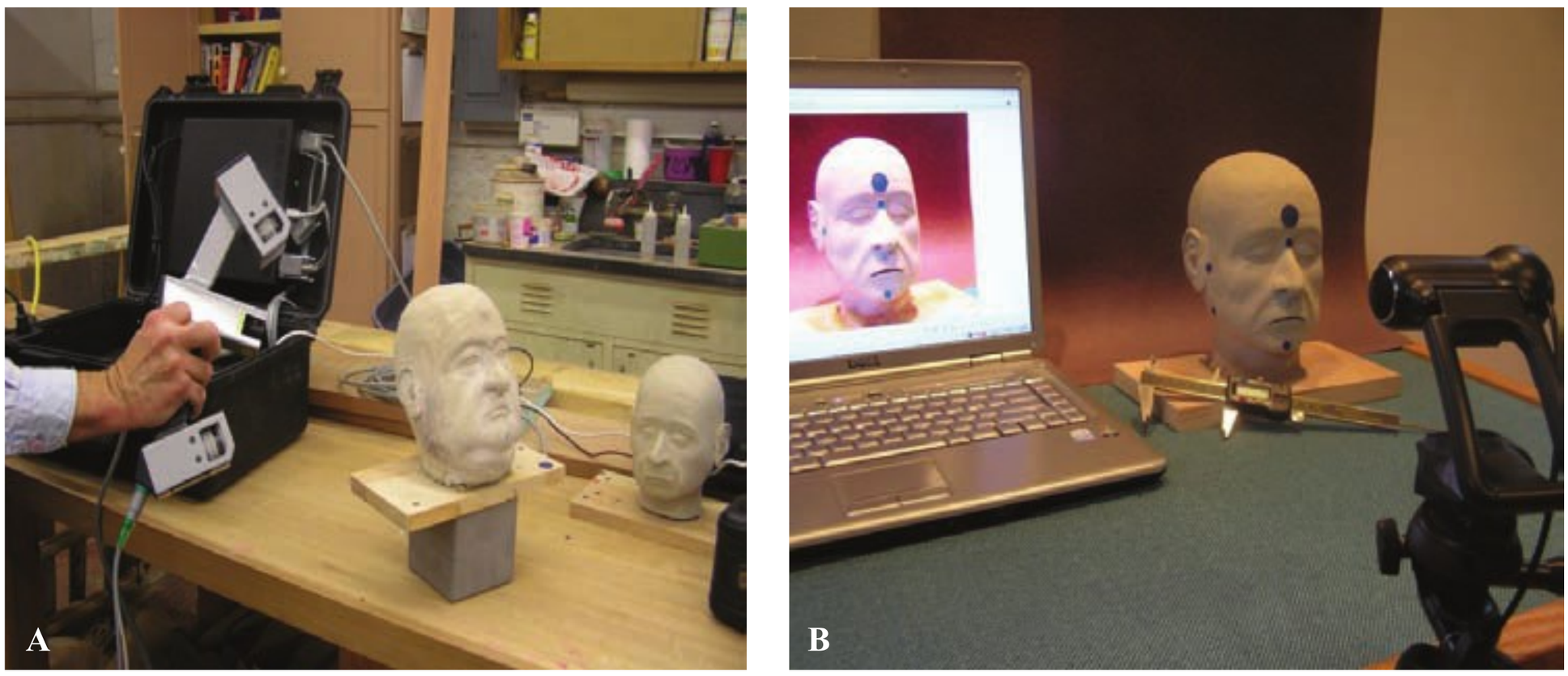


FIGURE 11-12 Comparison of 3-D craniofacial laser scanning **(A)** with 2-D photography **(B)** and surface measurements **(B)**.

the measurements of *linear* distances between *projections* of the anthropometric points into the *monoplanar* plane. Depending on the location of these points in the *3-D space*, these measurements may underestimate the true distance (Fig. 11-13). By comparing linear measurements obtained by the 3-D laser scanning and 2-D digital photography, we showed that this error can be as high as 30% of the actual distance (Table 11-1) and it is even higher when compared with the surface distances. The 2-D versus 3-D difference was especially large in abnormal heads suggesting that only 3-D laser scanning may yield accurate results in patients with abnormal head and neck anatomy (eg, morbid obesity).

The studies cited above have been performed either in the population of nonobese Japanese[23] or in selected groups of male Caucasians.[26] Because obesity is more

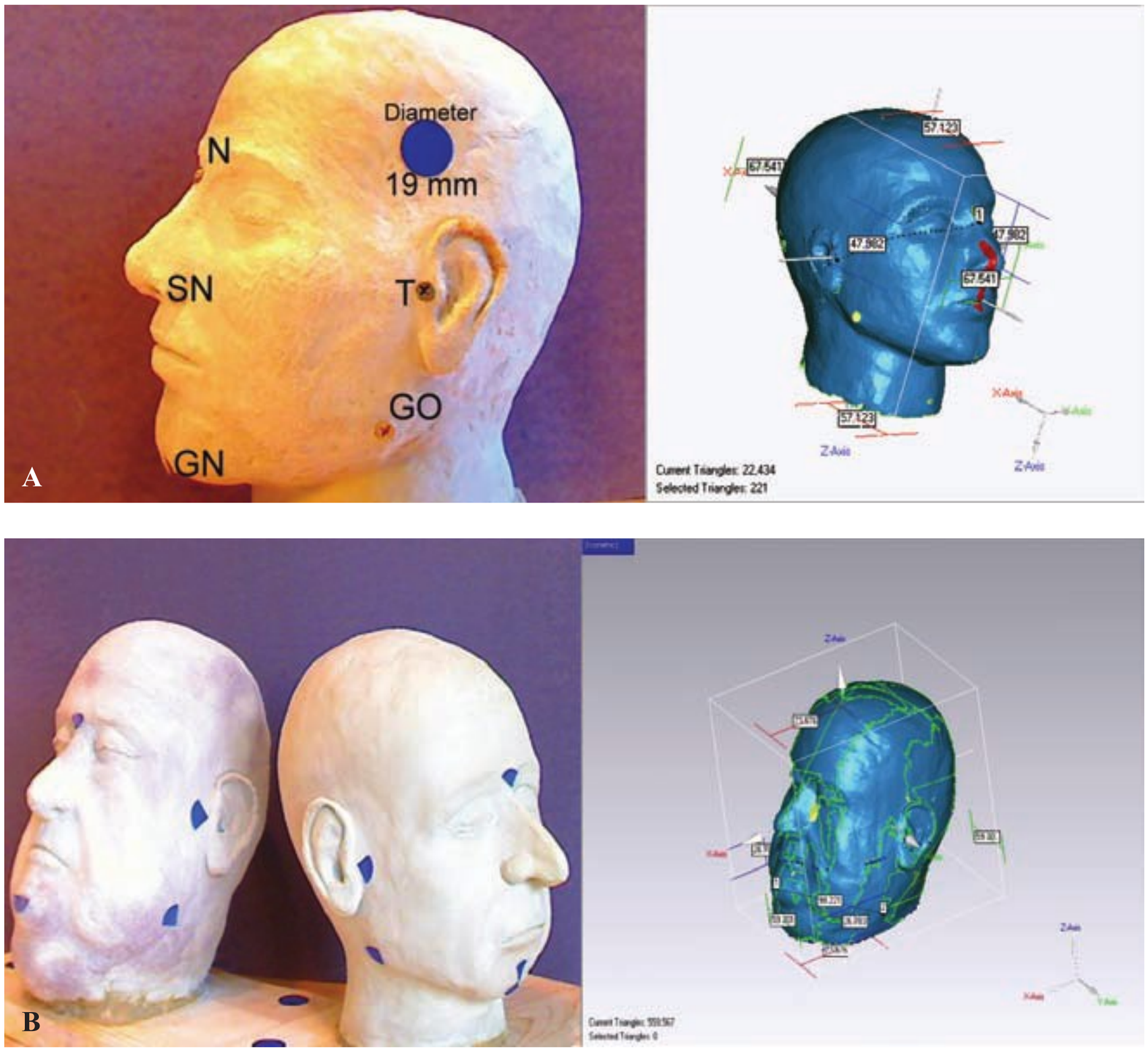


FIGURE 11-13 Laser scans of life-size normal **(A)** and abnormal **(B)** clay heads processed using specialized software that has allowed detailed and highly accurate curvilinear and volumetric craniofacial measurements.
T, tragion; N, nasion; SN, subnasion; GO, gonion; GN, gnathion

common in North America, only a large study in a diverse patient population with the use of 3-D scanning can confirm the validity of the proposed models and the whole concept of craniofacial phenotyping.

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CHAPTER 12

Decision Making in Difficult Airway Management

Tara Knizner and Cynthia Wells

Management of the airway is one of the primary responsibilities of anesthesiologists and physicians caring for critically ill patients. There are multiple clinical scenarios in which intubation of the trachea is indicated. In the operating room, intubation is necessary in order to ensure patency and protection of the airway in a patient rendered unconscious by anesthesia. When a patient is in acute respiratory distress or requires resuscitation, there is a requirement to maintain oxygenation and ventilation.

Complications related to airway management are one of the most frequently cited adverse outcomes associated with anesthetic delivery. These complications include death, brain injury, unnecessary tracheostomy, airway trauma, and damage to teeth (see Chapter 55).[1] Many of these catastrophic outcomes result from inability to secure the airway during attempts at management of difficult ventilation and/or intubation. In order to standardize management of the difficult airway, practice guidelines were developed by the American Society of Anesthesiologists (ASA) Task Force in 1993 and later revised in 2003. Since their implementation in the United States, morbidity, mortality, and claims related to airway management in the operating room have fallen significantly.[2]

When following the ASA Difficult Airway Algorithm, the two primary components of the initial patient assessment involves determining whether one may face difficulty with mask ventilation or tracheal intubation. As described in the previous chapter, there are multiple physical criteria used by physicians to identify patients that are at high risk (see Table 12-1).[1] Additional consideration must be given to whether the patient may have difficulty cooperating with awake attempts at intubation or whether one may face a difficult tracheostomy in an emergency setting. Furthermore, the airway examination may reveal the presence of severe airway anatomy or pathology that warrants an initial surgical approach. Other management options include maintenance of spontaneous ventilation versus attempting intubation after the induction of general anesthesia. Most often, if it is determined that there would be difficulty with ventilation or intubation, the option of an awake intubation is considered for the cooperative patient in order to maintain spontaneous ventilation. This technique increases the threshold of safety if problems are encountered with securing the airway. Table 12-2 lists techniques for management in these situations.[1]

One of the greatest challenges in airway management is the patient who does not demonstrate the above characteristics but presents difficulty in ventilation or intubation after being rendered unconscious. Therefore it is the responsibility of the anesthesiologist OR OTHER AIRWAY PROVIDER to always be prepared to manage the unanticipated difficult airway. Prior to the induction of every anesthetic, various airway tools should be readily available, including multiple rigid laryngoscope blades of various sizes, a gum elastic bougie, oral airways, laryngeal mask airways (LMAs), a 14G angiocatheter, and a functional manual jet ventilator.

If an attempt at intubation after induction of anesthesia is undertaken in a patient who has an airway exam that is less than ideal, the anesthesiologist should have additional tools for airway management immediately available. These, may include a rigid fiberoptic laryngoscope (eg, Glidescope), a fiberoptic bronchoscope, AN intubating LMA, A lightwand or a difficult airway cart that is equipped with various tools that can be used in the event of difficulty with intubation. The importance of being familiar with these tools and having them immediately available in the event of an unanticipated difficult airway cannot be overstated because prediction of the difficult airway is unreliable.

The ASA difficult airway algorithm specifically addresses the course of action to take in the event a difficult airway is encountered after the induction of general anesthesia (Fig. 12-1).[1] If initial attempts to intubate the patient are unsuccessful, then the anesthesiologist should consider calling for help, returning the patient to spontaneous ventilation, and/or allowing him/her to awaken provided that a short-acting anesthetic and muscle relaxants have been administered. The ability to call for assistance varies depending on the type of institution in which the anesthesiologist is practicing as well as the time of day. This situation changes dramatically if the anesthesiologist is the lone provider or is on call at night where he/she may be the only trained airway provider available. Similarly, intensivists, hospitalists, and emergency physicians who provide airway management services may find themselves

Table 12-1

Components of the Preoperative Airway Physical Examination

Airway Examination Component	Nonreassuring Findings
1. Length of upper incisors	Relatively long
2. Relation of maxillary and mandibular incisors during normal jaw closure	Prominent "overbite" (maxillary incisors anterior to mandibular incisors)
3. Relation of maxillary and mandibular incisors during voluntary protrusion of cannot bring	Patient mandibular incisors anterior to (in mandible front of) maxillary incisors
4. Interincisor distance	< 3 cm
5. Visibility of uvula	Not visible when tongue is protruded with patient in sitting position (eg, Mallampati class greater than II)
6. Shape of palate	Highly arched or very narrow
7. Compliance of mandibular space	Stiff, indurated, occupied by mass, or nonresilient
8. Thyromental distance	Less than three ordinary finger breadths
9. Length of neck	Short
10. Thickness of neck	Thick
11. Range of motion of head and neck	Patient cannot touch tip of chin to chest or cannot extend neck

This table displays some findings of the airway physical examination that may suggest the presence of a difficult intubation. The decision to examine some or all of the airway components shown in this table depends on the clinical context and judgment of the practitioner. The table is not intended as a mandatory or exhaustive list of the components of an airway examination. The order of presentation in this table follows the "line of sight" that occurs during conventional oral laryngoscopy.

From Practice guidelines for management of the difficult airway: an updated report by the ASA task force on management of the difficult airway. *Anesthesiology*. 2003;98:1269–1288, with permission.

Table 12-2

Techniques for Difficult Airway Management

Techniques for Difficult Intubation	Techniques for Difficult Ventilation
Alternative laryngoscope blades	Esophageal tracheal Combitube
	Intratracheal jet stylet
Awake intubation	LMA
Blind intubation (oral or nasal)	Oral and nasopharyngeal airways
	Rigid ventilating bronchoscope
Fiberoptic intubation	Invasive airway access
Intubating stylet or tube changer	Transtracheal jet ventilation
	Two-person mask ventilation
LMA as an intubating conduit	
Lightwand	
Retrograde intubation	
Invasive airway access	

This table displays commonly cited techniques. It is not a comprehensive list. The order or presentation is alphabetical and does not imply preference for a given technique or sequence of use. Combinations of techniques may be employed. The techniques chosen by the practitioner in a particular case will depend upon specific needs, preferences, skills, and clinical constraints.

From Practice guidelines for management of the difficult airway: an updated report by the ASA task force on management of the difficult airway. *Anesthesiology*. 2003;98:1269–1288, with permission.

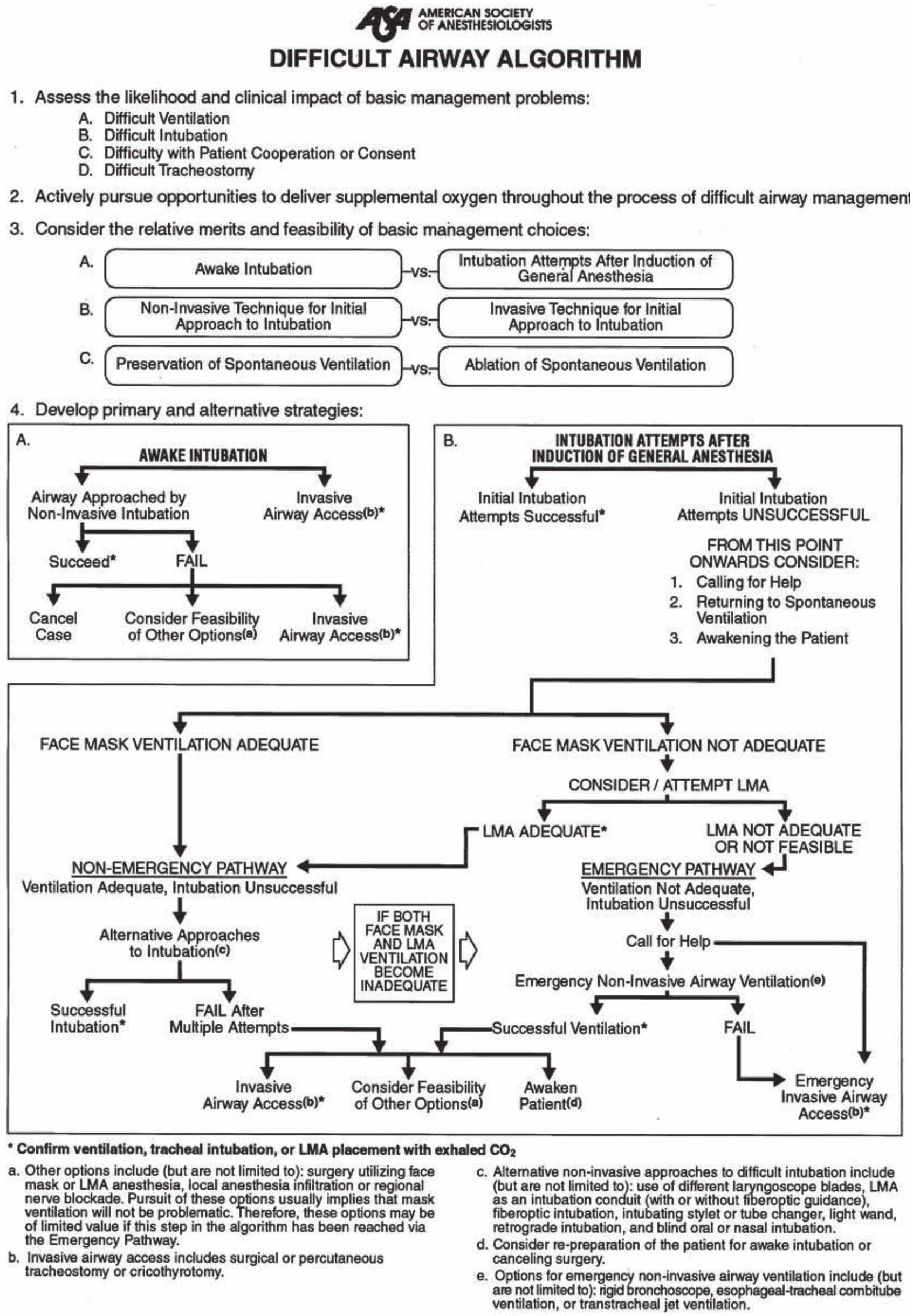


FIGURE 12-1 ASA difficult airway management algorithm.

(From Practice guidelines for management of the difficult airway: an updated report by the ASA task force on management of the difficult airway. Anesthesiology. 2003;98:1269–1288, with permission.)

unable to call upon "back up" because the settings and times of day that are involved often preclude this.

After multiple attempts to intubate via direct laryngoscopy have been unsuccessful (typically this should be limited to three or four attempts), the anesthesiologist must attempt to ventilate the patient via face mask. If face mask ventilation is adequate, then the situation is considered nonemergent and alternative noninvasive approaches can be attempted such as the use of different laryngoscope blades, LMA as an intubation conduit, fiberoptic intubation, intubating stylet, lightwand, or retrograde intubation. If one continues to encounter difficulties, adequate oxygenation must be maintained via face mask ventilation in between attempts.

When a patient cannot be ventilated by face mask, one has entered the emergent pathway of the difficult airway algorithm. In these emergent instances, the anesthesiologist must call for help and then attempt emergency ventilation-preferably using an LMA, although an esophageal-tracheal combitube or transtracheal jet ventilation may also be utillized (chapters 25, 26, 29). Because of its ease of insertion, rapid establishment of ventilation, familiarity to anesthesia personnel, and reliability in this setting, the LMA was emphasized as the preferred instrument for emergent ventilation when bag-mask ventilation fails, in the 2003 ASA guidelines.[1] If the patient can be oxygenated by one of these approaches, a decision must then be made to either allow the patient to emerge from anesthesia and resume spontaneous ventilation, to proceed with surgery using the above airway technique such as the LMA, or to establish a definitive airway. A definite airway may be indicated for emergency surgery, to prevent aspiration, or if the above technique is not adequate for long-term ventilation. Attempts to establish a definitive airway in these situations may include such techniques as passing an endotracheal tube through an LMA with or without fiberoptic guidance or performing a fiberoptic oral intubation during jet ventilation. If these attempts fail or if the patient's condition deteriorates further, invasive airway access must be established BY EITHER emergent tracheostomy or cricothyrotomy by open or percutaneous approaches (chapters 36 through 39). In the operating room, trained surgical personnel are often available to perform the emergency invasive airway.

Many institutions have implemented a comprehensive program designed to address management of the difficult airway. In these institutions, there are certain standard procedures performed in the event that a difficult airway is unexpectedly encountered. For example, as cited in the difficult airway algorithm, one of the first steps in dealing with a difficult airway is calling for help. This is usually accomplished via a code button in the operating room suite or an overhead airway paging system in order to notify trained anesthesia personnel of the location of an airway emergency. In addition, other support staff may be trained to obtain difficult airway equipment during these situations. The contents of difficult airway carts are fairly standard throughout most institutions, and they should contain all of the necessary equipment to assist in establishing an airway. Table 12-3 lists the recommended contents of these carts, according to the ASA guidelines.[1]

Another aspect of the program includes standardized training in difficult airway management for all anesthesia personnel on a regular basis. Many institutions use simulation situations for training purposes (see Chapter 13, 14). Commonly, this involves a simulation mannequin and a staged scenario in which multiple anesthesia personnel manage the difficult airway. Various studies have been conducted to examine the efficacy of simulation training on adherence to the ASA difficult airway algorithm. Some of these have shown simulation to be useful in training of management of emergency situations in anesthesia[3,4] and as a tool to reinforce algorithms for anesthesia residents.[5] However, one recent study illustrated that in a group of experienced anesthesiologists, despite simulation training, there was incomplete adherence to the ASA algorithm during a repeated simulation of a cannot intubate, cannot ventilate scenario.[6] In a recent retrospective database review conducted at Johns Hopkins University School of Medicine, it was determined that a comprehensive difficult airway program reduced the need for emergency surgical airways. It was determined that despite an increase in the number of patients reported to have a difficult airway and an overall increase in the number of patients receiving anesthesia that the incidence of emergency surgical airway procedures decreased after institution of a comprehensive difficult airway program.[7] Finally, with the implementation of electronic medical records, many institutions have the option of documenting whether a patient has a known difficult airway. This allows the practitioner to adequately prepare for the management of the airway, which may involve performing an awake intubation.

Although most situations requiring airway management occur in the controlled environment of the operating room suite, management of the airway in other areas of the hospital provides additional challenges. Many patients present to the emergency department as a result of trauma or respiratory failure, and these patients often require emergent intubation. Table 12-4 lists the differences between an emergent and nonemergent airway. Often the circumstances associated with an emergent airway can increase the likelihood of morbidity to the patient. For example, in an emergent intubation, there is no time to adequately preoxygenate a patient as the preparatory time to intubation is seconds rather than minutes. The patient often is breathing room air (FiO2 = 21%) prior to apnea as opposed to 100% oxygen. This decreases the apneic time to desaturation making it necessary to intubate the trachea quickly. Unlike patients

Table 12-3

Suggested Contents of the Portable Storage Unit for Difficult Airway Management

1. Rigid laryngoscope blades of alternate design and size from those routinely used; this may include a rigid fiberoptic laryngoscope
2. Tracheal tubes of assorted sizes
3. Tracheal tube guides. Examples include (but are not limited to) semirigid stylets, ventilating tube changer, lightwands, and forceps designed to manipulate the distal portion of the tracheal tube
4. LMAs of assorted sizes; this may include the intubating LMA and the LMA-Proseal (LMA North America, Inc., San Diego, CA)
5. Flexible fiberoptic intubation equipment
6. Retrograde intubation equipment
7. At least one device suitable for emergency noninvasive airway ventilation. Examples include (but are not limited to) an esophageal tracheal Combitube (Kendall-Sheridan Catheter Corp., Argyle, NY), a hollow jet ventilation stylet, and a transtracheal jet ventilator
8. Equipment suitable for emergency invasive airway access (eg, cricothyrotomy)
9. An exhaled CO_2 detector

The items listed in this table represent suggestions. The contents of the portable storage unit should be customized to meet the specific needs, preferences, and skills of the practitioner and health care facility.

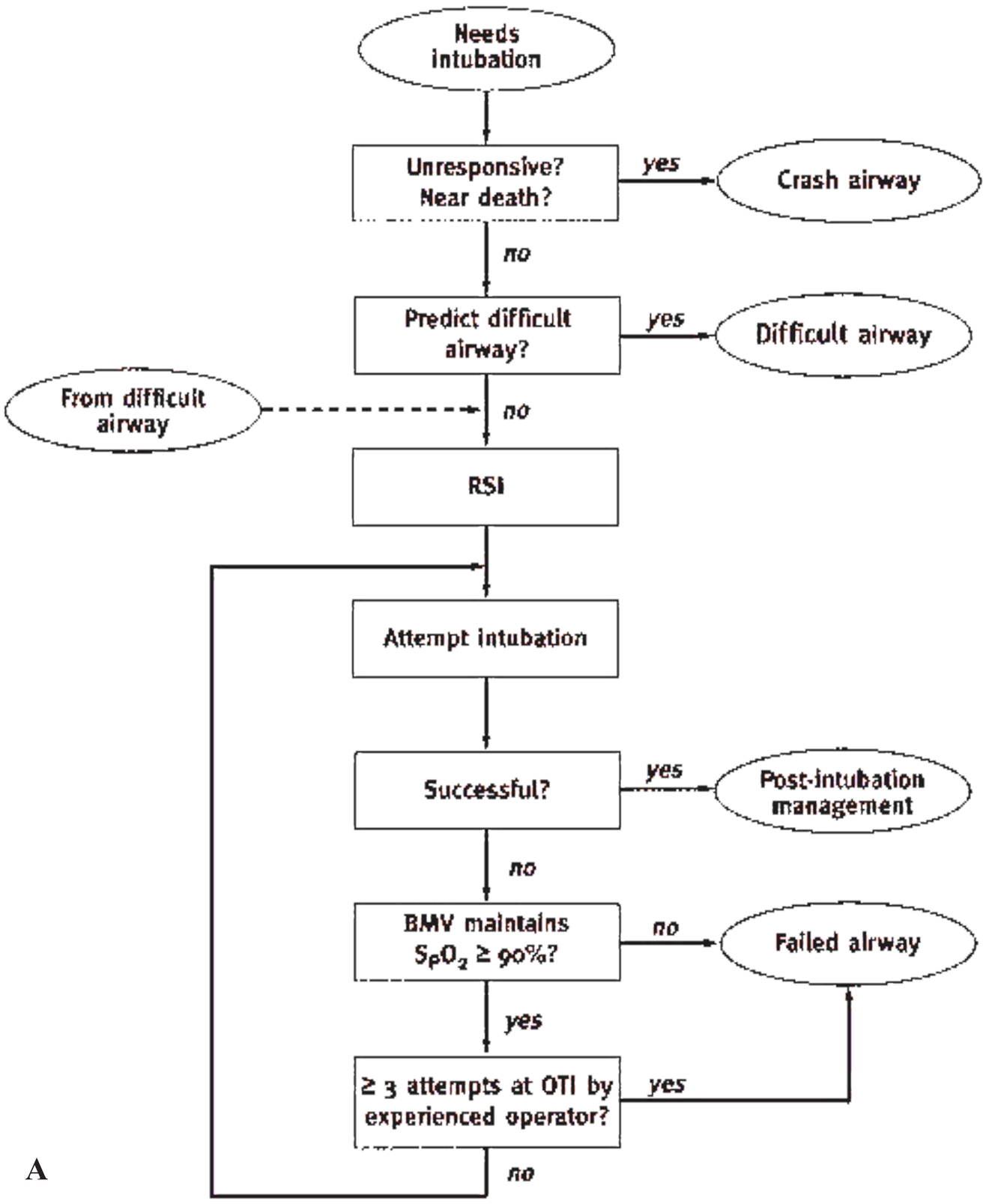
From Practice guidelines for management of the difficult airway: an updated report by the ASA task force on management of the difficult airway. *Anesthesiology*. 2003; 98:1269–1288, with permission.

Table 12-4

Differences in Airway Management Requirements between Elective operating room Cases and Emergency Situations

Aspects of Airway Management	Elective Cases in Operating Room	Emergent Cases
Goals	Assure patent airway and ventilation while patient is unconscious	Obtain definitive airway, ensure ongoing ventilation and oxygenation, control secretions
Patient Characteristics	Respiratory system intact Fasted	Respiratory failure common Presumed full stomach
Preparatory time	Hours to days	Seconds to minutes
Alternatives for failed airway	Emphasis on awakening patient to allow resumption of spontaneous ventilation	Must progress to definitive airway

scheduled for an elective procedure who have fasted for 8 hours or more, the patients presenting to the trauma bay are considered to have a full stomach and are treated with precautions such as cricoid pressure (i.e., Sellick maneuver) and rapid sequence intubation in order to minimize the risk of pulmonary aspiration of gastric contents. Patients involved in trauma require cervical spine stabilization during intubation, which can make it difficult to align the oral, pharyngeal, and laryngeal axis, limiting the view of the glottic opening. In addition, the view of the vocal cords can be further limited by the presence of blood and/or secretions in the pharynx. See Figure 12-2 for one example of an airway management algorithm used by emergency physicians.[8]



A

FIGURE 12-2 Emergency medicine airway management algorithms. **A:** Routine airway management algorithm. **B:** Algorithm for "crash airway" when there is no time for patient assessment or preparation and the need for an airway is emergent. **C:** Algorithm for predicted difficult ventilation and/or intubation. **D:** Algorithm for "failed airway" when intubation by attempted direct laryngoscopy could not be accomplished. (From Walls RM, ed. *Manual of Airway Management*. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2004:8–21, with permission).

FIGURE 12-2 (Continued)

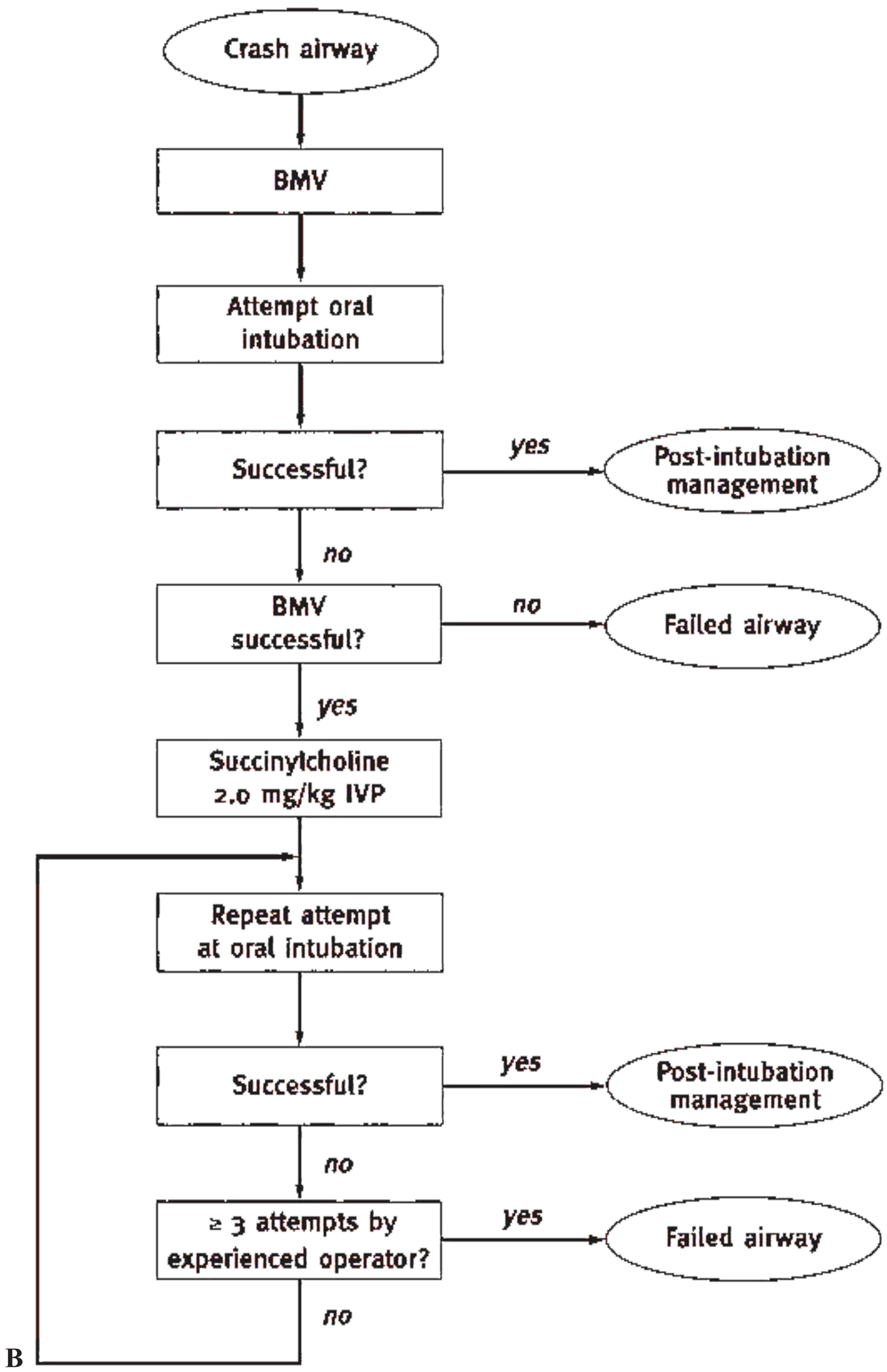
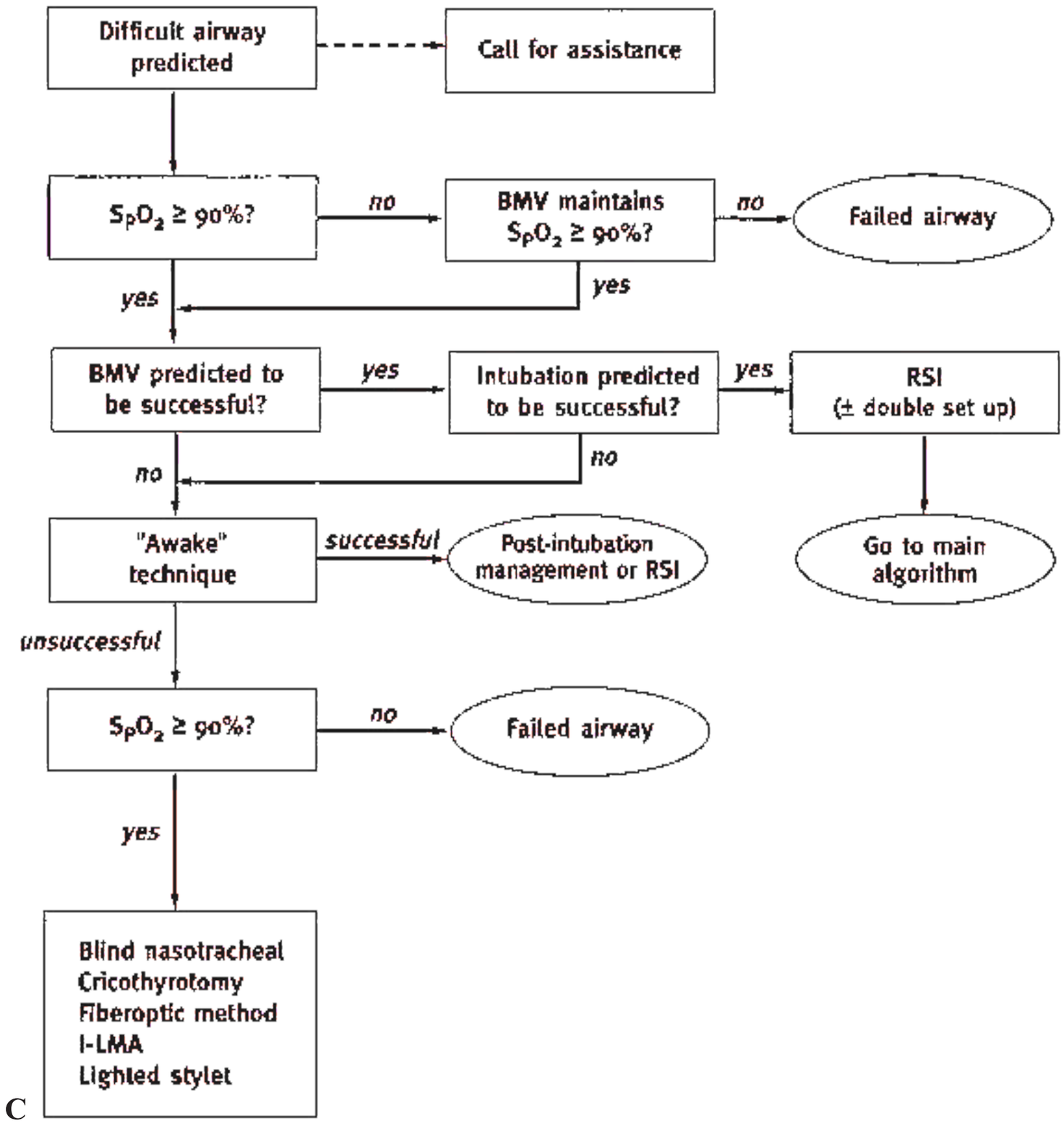


FIGURE 12-2 (Continued)



C

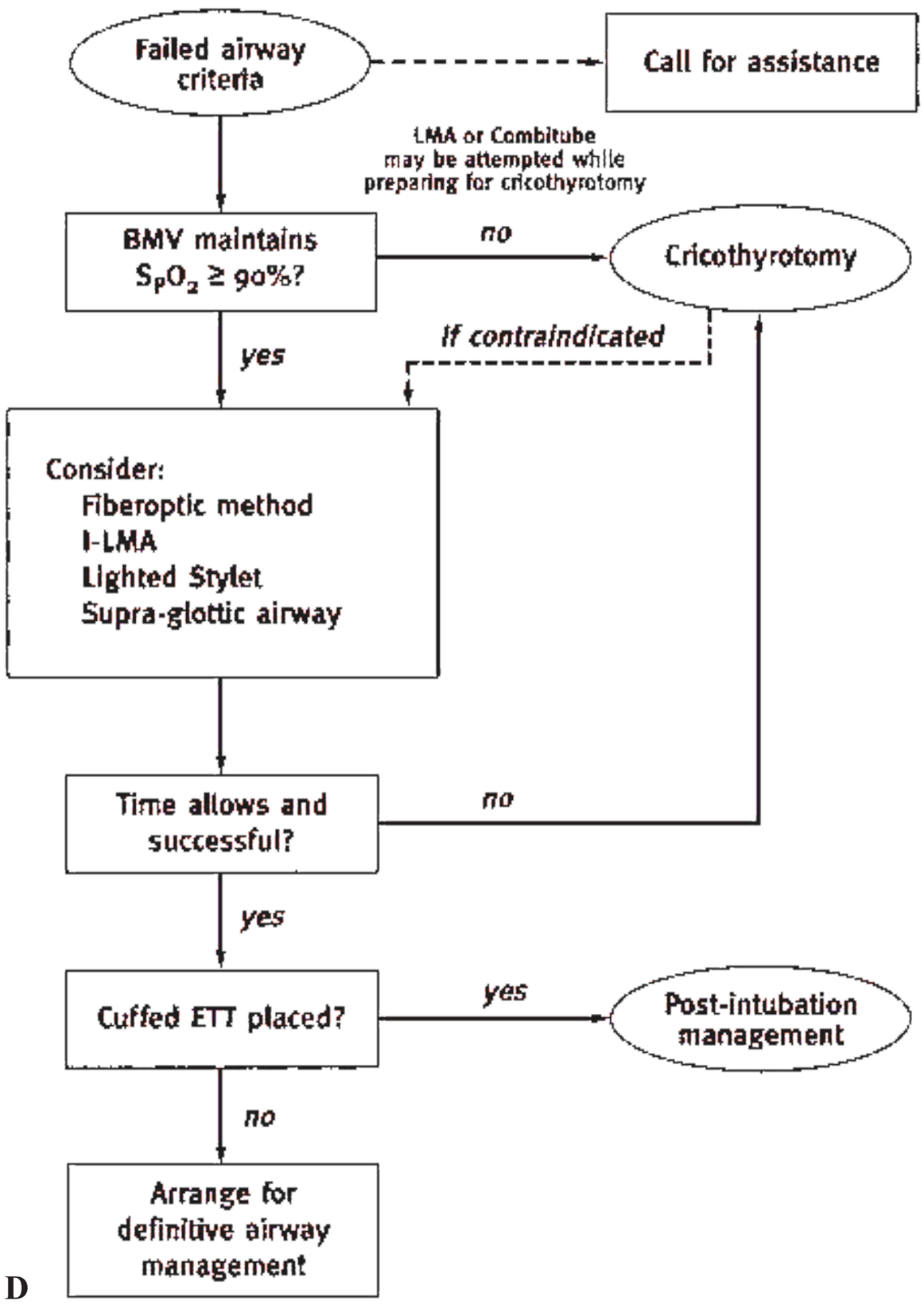


FIGURE 12-2 (Continued)

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CHAPTER

13

Training in Airway Management: Difficult Airway Simulation

Scot Muir and Joseph Quinlan

A difficult airway is defined by the American Society of Anesthesiologists (ASA) as "the clinical situation in which a conventionally trained anesthesiologist experiences difficulty with face mask ventilation of the upper airway, difficulty with tracheal intubation, or both."[1] A mismanaged difficult airway is often an immediate threat to the patient's life. Therefore, it is essential for all anesthesiologists to be experts in difficult airway management (DAM). Although analysis of the ASA closed claim database suggests that implementation of the ASA DAM algorithm over the past two decades has reduced the number of failed difficult airways during induction of anesthesia,[2] outcomes in simulated DAM indicate that a significant percentage of currently practicing anesthesiologists are poor managers of the difficult airway, with up to a third of simulated emergent pathway airways ending in simulated death.[3,4] There are two factors that probably contribute to this lack of expertise. First, the ACGME requirements for training in DAM during residency are remarkably nonspecific,[5] and there are understandably a wide variety of approaches to teaching management of the difficult airway. Second, DAM is not an everyday occurrence. It has been estimated that encountering a difficult airway is a relatively rare event. In one particular study, there were 100 out of 11,257 unanticipated difficult intubations.[6] Difficult ventilation, however, seemed even more rare with 6 of 11,257 being difficult but 0 of 11,257 being classified as impossible ventilations.[6] It may be difficult for many anesthesiologists to gain enough experience to become and remain expert difficult airway managers based solely on their residency training and clinical experience. Thus, it is imperative for the anesthesiologist to receive additional training in DAM beyond everyday clinical experience.

Simulation provides experience to the learner in a more controlled and structured environment than is possible in the clinical arena. Simulation of the difficult airway is in many respects the most ideal method to learn DAM. Advantages of simulation as opposed to in vivo training include (1) improved safety to the patient, (2) the ability for increased exposure to unlikely or rare scenarios, (3) the ability to manipulate and customize those scenarios, and (4) decreased incidence of malpractice claims.[7]

There are several concerns that must be addressed before any simulation program can be accepted as a suitable tool for teaching DAM and measuring competence in DAM. The chief concern is validation, that is, does the simulation program truly measure what it purports to measure? Can the simulation environment reproduce the events normally encountered in the clinical arena? Do the tools used clinically function in the expected way in the simulation environment? Does the simulation program define competence in a way that most experts in the field would endorse? Can it reliably discriminate between an expert and a novice? Is the measurement of competence in a given subject reproducible over repeated measures? How long does the effect of the training and measurement last (ie, retention)? These concepts are vital in assessing the effectiveness of any educational program, but particularly so in the field of simulation which has been plagued in the past by a relative lack of effectively validated studies.[8]

Fortunately, validity has been shown to be high in regard to many aspects of DAM simulation. The primary factor responsible for this is the existence of the ASA Difficult Airway Algorithm, which provides a peer-reviewed gold standard for the management of the difficult airway. It has been shown that DAM simulation courses seem to have high correlation with clinical scenarios.[9,10] This is probably because most scenarios are based on events that have occurred in the clinical realm. It has also been shown that there is high validity of the actual specific airway techniques for the Laerdal Simman.[11] The validity of DAM simulation is not confined just to anesthesiology but also appears to extend to other medical specialties as well as to prehospital providers.[12,13] Finally, it appears that various DAM courses that are designed with a structured curriculum produce similar results.[12,13]

Reliability has also been shown to be very high for DAM simulation. There has been significant intratrainee reproducibility within a DAM simulation course.[14] DAM simulation can reliably discriminate between experienced, competent airway managers and novices who would not be expected to be competent.[9]

The question of how long DAM skills taught using simulation are retained remains unanswered and will require additional research. Early data suggested that DAM skills taught via simulation were reasonably well maintained at 1 to 3 years after initial training.[15] Other recent data, however, showed that it may be necessary to repeat DAM simulation every 6 months or less.[16] This data showed that skills acquired for cannot intubate/cannot ventilate were retained for approximately 6 to 8 months, but the skills acquired for cannot intubate were only retained for 6 to 8 weeks.[16] Length of retention is likely related to how often the anesthesiologist encounters the difficult airway in daily clinical practice.

As simulation has become more widely accepted as a vital tool for teaching and assessing DAM, more of the most prestigious anesthesiology residencies are implementing structured simulation courses in DAM for residency training. In addition, the American Board of Anesthesiology has recognized DAM simulation as one of the core areas eligible for its Maintenance of Certification in Anesthesiology program and is working with the ASA Simulation Network to increase opportunities for practicing anesthesiologists to obtain additional simulation training in DAM.[17]

At UPMC, the Winter Institute for Simulation, Education, and Research (WISER) plays a vital role in training residents, fellows, and attending physicians in DAM. There are three courses that share a basic curriculum and format but in which the specific simulation scenarios are tailored to the specialties in which DAM is crucial. These specialties included are anesthesiology, critical care medicine, and emergency medicine. The courses taught to anesthesia and critical care medicine (CCM) providers are very similar, whereas the DAM course taught to emergency medicine physicians focuses on how to quickly assess an airway and how the difficult airway applies to rapid sequence intubation. All courses are structured around the ASA Difficult Airway Algorithm. Our residency has required that all anesthesiology residents attend the Anesthesiology DAM course each year during their CA-1 through CA-3 years, for more than a decade. All anesthesiology faculty at UPMC must complete the Anesthesiology DAM simulation prior to being granted medical staff privileges in anesthesiology.

We will focus on the DAM course for anesthesiologists (Table 13-1 for outline) and present a sample simulation scenario. The objectives of the Anesthesiology DAM course are for each participant to (1) develop a "working" knowledge of the ASA difficult airway algorithm, (2) develop confidence and proficiency in performing the various difficult airway techniques, and (3) develop expertise and confidence in applying the ASA difficult airway algorithm through managing simulated difficult airway scenarios in real time. Each DAM scenario then has its own, more specific objectives.

The entire curriculum of the course is posted online, and participants are expected to review the material prior to attending the course. Prior review is assessed using a short quiz at the beginning of the course. Participants then perform four simulated airway scenarios that assess their ability to apply the ASA difficult airway algorithm in real time. This provides a baseline assessment of the participant's strengths and weaknesses prior to any training. Feedback and discussion about the participant's performance is provided after the completion of the scenarios.

Following the baseline assessment scenarios, the instructor delivers a short didactic lecture. The lecture reviews basic science concepts such as the time course of oxyhemoglobin desaturation during apnea, anatomy of the airway, and the structure of ASA difficult airway algorithm. The core of the course consists of an in-depth review of all of the tools approved for use within the ASA difficult airway algorithm (laryngeal mask airway, intubating laryngeal mask airway, Combitube, transtracheal jet ventilation, cricothyrotomy, percutaneous cricothyrotomy, retrograde intubation, lighted stylet, and fiberoptic bronchoscopy) as well as several that are not yet included in the algorithm (video laryngoscopy, tube exchangers). This is accomplished using short video clips coupled with an extended skill practice session on the mannequin simulators. Participants are encouraged to practice use of each airway tool to the point that they are confident that they could use them in a patient the next day. Once participants are confident of their ability to use the individual airway techniques, they then practice DAM scenarios until they are confident of their ability to apply the ASA difficult airway algorithm in real time. The DAM course then ends with four scenarios that again assess the management of various difficult airway situations. Tables 13-2 and 13-3 show sample scenarios a participant may be trained on. Table 13-2 shows the information the participant has access to and Table 13-3 shows the information that the instructor has access to. Figures 13-1 and 13-2 show the corresponding monitors and computer simulation control that accompanies each scenario. Figure 13-1 is the monitor the participant sees during the case and which vital signs change in response to how they manage the scenario. Figures 13-2, 11-3, and 13-4 show the screen view that the instructor has and is able to manipulate based on the actions of the participant. A simulator with scripting allows those who are not experts in simulation to easily and reliably administer simulated airway scenarios.

Table 13-1

An Outline for the Progression of a DAM Simulation Course

Outline of Course

1. Establish objectives
2. Scenarios—baseline
3. Feedback on scenario performance
4. Didactics
   a. Basic science concepts
   b. Airway assessment
   c. ASA algorithm
5. DAM tools/techniques—LMA, Combitube, FOB
   a. Didactics
   b. Practice on simulator
6. Scenario—assessment

Table 13-2

Sample Scenario: The Information the Participant is Given at the Beginning of a Simulation Scenario

Sample Airway Scenario: Unanticipated Difficult Airway after Induction of General Anesthesia for Emergent Caesarian Section

Participant Information

Setting:	You are the lone anesthesia caregiver on call at a small town rural hospital. At 1 in the morning you are asked to emergently provide a general anesthetic for a young female for a stat c-section.
Patient:	The patient is a 25-y-old female with preeclampsia who has a decreased fetal heart rate (80) for 4 min.
History:	**PMH:** G2 P1 with preeclampsia with current pregnancy **PSH:** Tonsillectomy at 5 y.o. GA without reported complications **MEDS:** Nubain 5 mg i.v. q2h prn pain **ALLERG:** NKDA **NPO:** 14 h **ROS:** neg. tob/Etoh, neg. cardio-pulm., neg. hepato-renal **PE:** 5′6″, 85 kg, temp. 37°C, BP 180/95, lungs-CTA, cor- RRR **LABS:** plt 40,000, HCT 38, K 4.0, bleeding time 3 min (normal 1–2.5)
Associated information:	The surgeon wishes to begin this emergent c-section ASAP.
Equipment available:	• Macintosh/Miller blades • Fiberoptic bronchoscope • LMA/Fastrack LMA • Esophageal-tracheal Combitube • TTJV • Cricothyrotomy kit • Lighted stylet • Retrograde kit • Gum bougie • ETT exchangers • Various oral and nasal airways

Written by: David Metro, MD for WISER DAM Simulation Course.

Table 13-3

Sample Scenario: The Information the Instructor has Access to and is Able to Manipulate. There are Specific Criteria for the Instructor to Follow Based on the Actions of the Trainee

Instructor Information

Facilitator Guidelines for Sample Scenario: Unanticipated Difficult Airway after Induction of General Anesthesia for Emergent Caesarian Section

Scenario Objectives:

1. Appropriately recognize that this scenario immediately leads to the "Emergent Pathway."
2. Consider returning to spontaneous ventilation.
3. Consider awakening the patient but realize that the patient is desaturating too fast for this strategy to work.
4. Call for appropriate help and equipment.
5. Identify the appropriate options for emergency airway ventilation.
6. Demonstrate effective psychomotor skill sets applying these options.
7. Identify the appropriate options for emergency surgical airway ventilation.
8. Demonstrate effective psychomotor skill sets applying these options.

Overview:

The patient is a young, previously healthy, female who presents for an emergent cesarean section. Induction of anesthesia will lead to a "cannot intubate, cannot ventilate" emergency. After induction, she will die within 5 min if an airway is not obtained. The scenario is geared toward obtaining an emergency surgical airway, though proper TTJV will also succeed.

General type of case:

Cannot intubate, cannot ventilate, 5 min desaturation, only TTJV and cricothyrotomy will work.

Simulator Setup:

Standard Prep, hand jet vent. flow control turned off (the trainee should be expected to check this).

Airway History and Examination:

Oral opening three fingerbreadths, Mallampati 3-nl. dent.-TMD 3 fingerbreadths-CROM 35° cricoid membrane palpable-trachea midline.

General Guidelines for Airway Scenario:

1. Lay out the "Equipment Available."
2. Make sure that hand jet ventilator pressure regulator is turned off. Unless trainees are familiar with the device, they will think it does not work.
3. Choose Scenario Version IA. When the trainee is ready click on Start Test. Patient will be conscious and ready for induction.
4. Pulse oximeter will drop from 100% to death over 5 min if an airway is not established correctly (TTJV or cricothyrotomy).
5. FTLMA, LMA, or Combitube are proper choices but will not work in this scenario (choose low-pressure failure for them if attempted).
6. The patient will not return to spontaneous ventilation or wake up. The only options that will successfully save the patient are either cricothyrotomy or TTJV within 5 min of induction.
7. Use the "ASA Difficult Airway Algorithm" performance checklist to guide debriefing of scenario.
8. Use the "ASA Difficult Airway Algorithm" poster as a teaching aide.
9. Review and offer correction of either psychomotor skill sets or knowledge/judgment errors. Let the trainee practice a skill set till successful.

(Continues)

Table 13-3 (Continued)

Simulation Instructions for Airway Scenario:

WHEN	WHAT	HOW
Prior to induction clinically create nl.	Airway	Press "clear all" button
Immed. after induction	Clinically create cannot intubate or ventilate	Press "cannot intubate/ventilate" button
When TTJV or cric. attempted	Clinically to make TTJV or cric. work	Press "decr. Pulm. Compl." button
After 1 min has elapsed	Start to decr. SaO_2	Press "decr. SaO_2" button till =98%
After 2 min have elapsed if airway not established	Decrease SaO_2 further	Press "decr. SaO_2" button till =90%
After 3 min have elapsed if airway not established	Decrease SaO_2 further	Press "decr. SaO_2" button till =80%
After 4 min have elapsed if airway not established	Decrease SaO_2 further	Press "decr. SaO_2" button till =70%
After 5 min have elapsed if airway not established	Decrease SaO_2 further till hypoxic death	Press "decr. SaO_2" button till =40%
If airway is established	Increase SaO_2, allow CO_2 detection	Press "incr. SaO_2" button till =98%, Press "CO_2 on" button

Written by: David Metro, MD for WISER DAM Simulation Course.

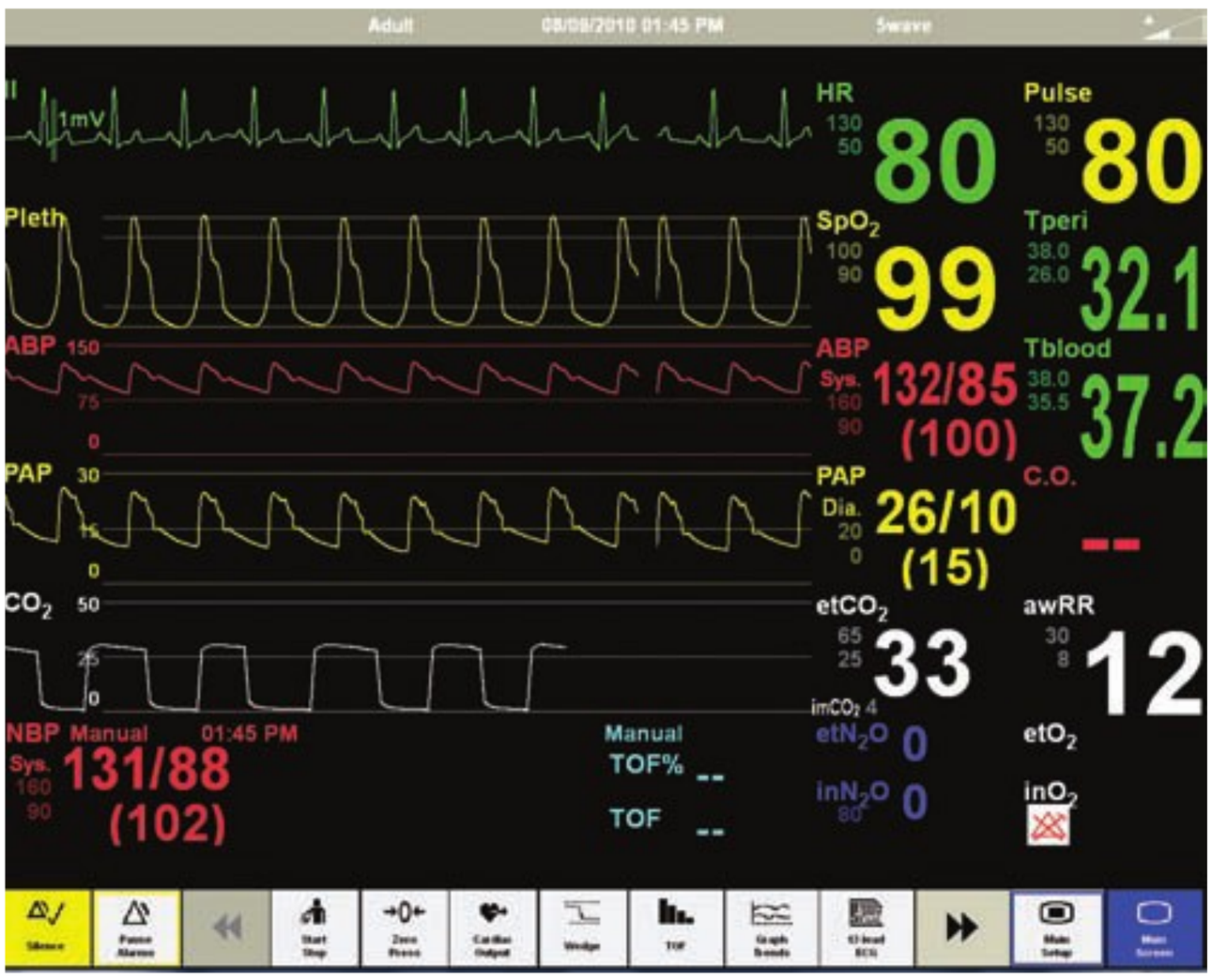


FIGURE 13-1 A view of the actual monitor screen that the participant sees throughout the case. All the vital signs are manipulated via the instructor's control panel.

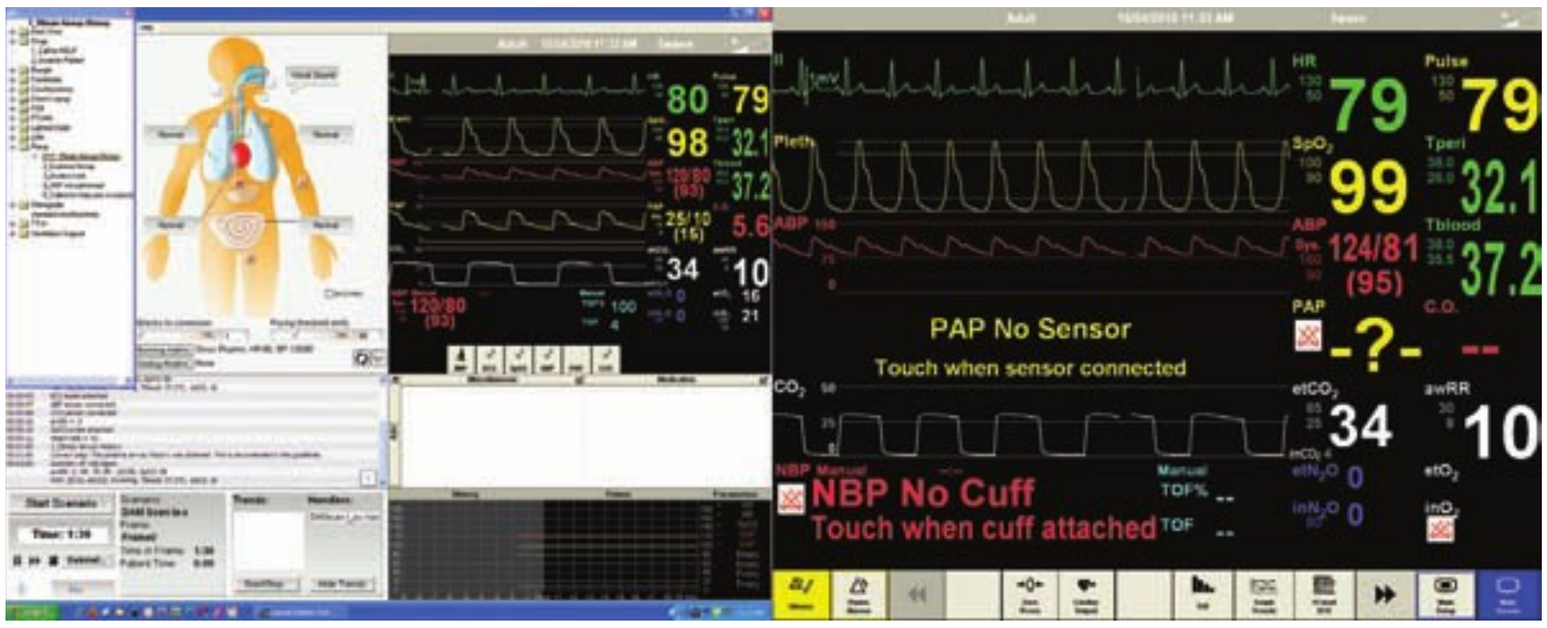


FIGURE 13-2 A screen capture from a computer driving a Laerdal Simman during an airway simulation. Note the undocked ABC window in the upper left corner. The trainer only needs to click on the relevant action in this window, and the script executing the scenario will automatically configure the simulator appropriately for that action. The upper center section shows a schematic of the simulator indicating its current state. The screen in the upper right corner shows the vital signs that are presented to the trainee. The lower right corner shows the long-term trends in hemodynamic data that the script will execute over the course of the next few minutes as the scenario plays out.

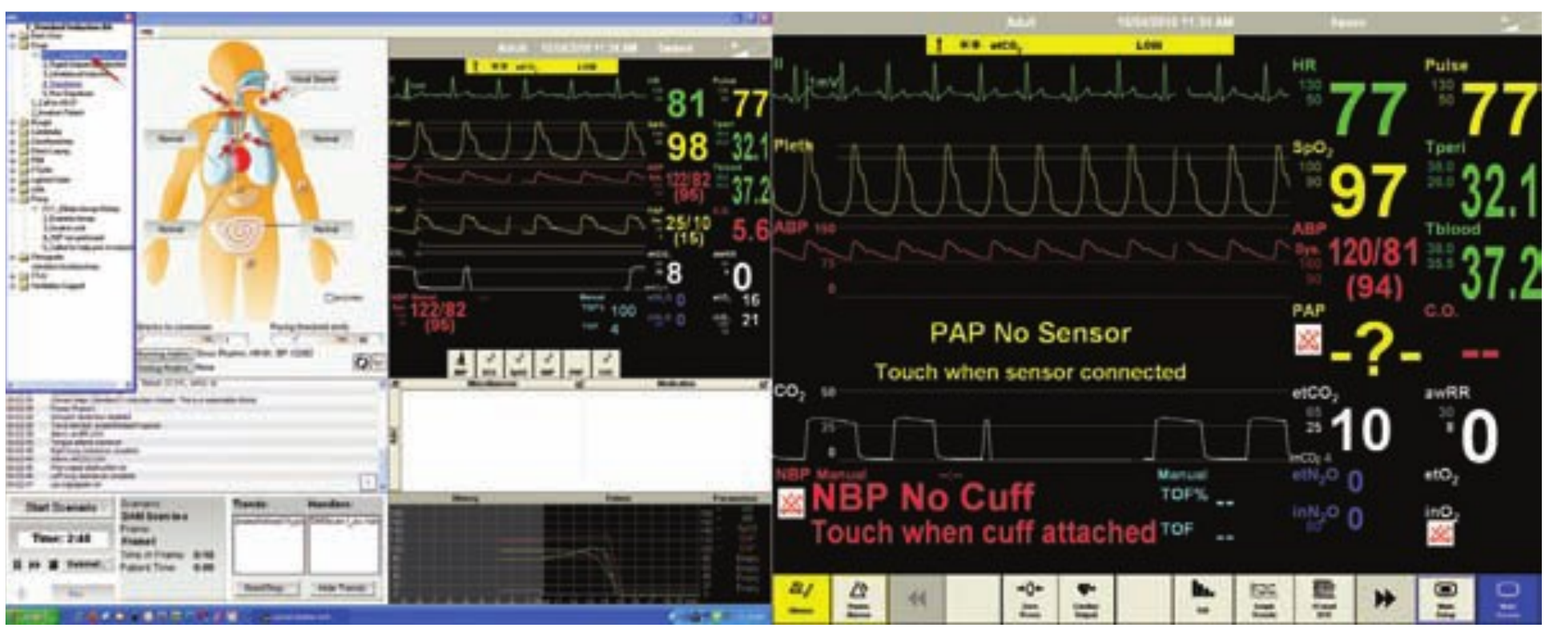


FIGURE 13-3 The trainer has clicked on the "Standard Induction of GA" selection in the ABC window as indicated by the single arrow. Note that the simulator has now been automatically transformed by the scripting engine into a cannot ventilate, cannot intubate configuration (multiple arrows in the upper center section). Note also that the hemodynamic trends indicate a hypoxic arrest will occur in approximately 5 minutes.

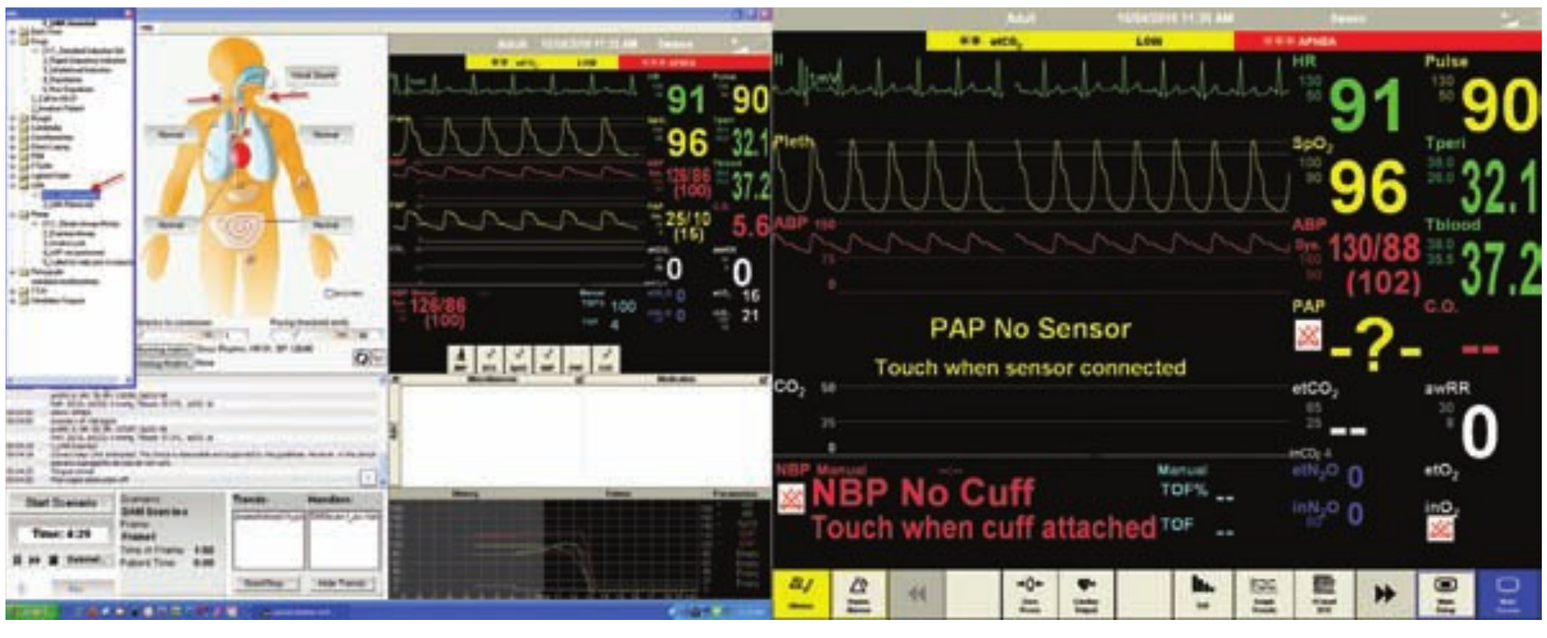


FIGURE 13-4 In the same scenario, the trainee has chosen to place a laryngeal mask airway, so the trainer clicks on this selection in the ABC window. The simulation is configured to allow the LMA to be placed (two arrows in the center section), but it still will not allow successful ventilation of the simulator.

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CHAPTER 14

Training in Airway Management

Mark Lischner and James Snyder

This chapter simplifies alternatives to airway training in terms of polar opposites, neither of which exists in pure form, to provide a framework for understanding the value of specific concepts and maneuvers.

In experience-based training, skill is acquired primarily through practice with elective surgery patients, initially with expert supervision, then with support immediately available for routine cases as skill develops. Because risk is low, multiple laryngoscopies are acceptable and independence and efficiency can be priorities. Call for assistance is a sign of failure, independence a sign of personal skill.

After basic skills are acquired, practiced use of endotracheal tube introducers (ETI) in simulated epiglottis-only cases is now considered fundamental to airway management. However, low learning trajectories suggest substantial dependence on experience. For example, anesthesiology residents required three or more attempts to intubate in 14.5% of emergency cases in their first clinical year, 10.4% in their second year, and 9% in their third, compared with 6.3% by attending staff (Fig. 14-1).[1]

In contrast to experience-based training, careful preparation for "first pass success" has been emphasized by Levitan and others to address different clinical and training program needs.[4–6] The focus is on optimal care of critically ill patients and achieving highest possible success rate with least patient risk. Ideally, the end-product is a smoothly coordinated sequence of maneuvers that achieves optimal glottic exposure and enables even novices first pass success despite unpredicted difficulty. The educational structure that leads to firstpass success is related to reverse engineering to understand individual skills and provision of support during intubation that allows exploration and practice of each skill independently, then in combination with other skills. Every case is presumed an unpredicted difficult intubation, justifying planned incorporation of passersby as assistants and emphasis on navigational tools to ensure the objective, and application of every support until exposure is optimal rather than adequate. Skills are acquired via "dry lab" simulation and cadaver training when available. In every case, trainees are encouraged to prepare for advanced techniques in case of unpredicted difficulty and to maximize success despite their limited experience.

Shorter learning curves have been reported by emergency medicine (EM) and critical care medicine (CCM) training programs that focused on patients at greater risk. In programs designed to manage airways of critically ill patients, performance after 6 months experience was comparable to critical care attendings with an anesthesiology background,[7] and EM resident performance in postgraduate years 3 and 4 were comparable to anesthesiology residents in postgraduate years 2 to 4.[8] In a program where total experience may be less than 200 cases, EM resident intubation success rate in a trauma emergency room was 97%.[9]

At the University of Pittsburgh Medical Center about half of the more than 20 physicians who start CCM fellowship each year are airway novices. Dispersion of responsibility throughout the hospital requires novices with minimal training opportunity unavoidably to serve as first responders at emergent events. Despite excellent support by operating room (OR) anesthesiology attending staff, program requirements entail clinical responsibility before training described above for EM programs can be provided. Although CCM attendings are in-house and attend codes 24/7, proximity and multiple simultaneous events result in potential for unsupervised novices being the first responders to codes. Advance training using cadavers has been restructured to assertively apply advanced airway skills, including first pass success as championed by Levitan.[4–6] Novice CCM fellows self-reported success in 85% (78% first pass) of their first 99 intubations of critically ill patients in 2007 (10 fellows, mean 7.6, range 1 to 13).[10] Data collection was not quality-controlled well in this pilot study; subsequent quality-controlled data are now being analyzed.

Factors that favor accelerated training in airway care and techniques that appear to accelerate the success rate and/or patient safety are summarized in Tables 14-1 and 14-2.

Although there is need for increased and accelerated training and the number of cases is declining, several factors may weigh against incorporation of the first pass approach to direct laryngoscopy (DL) (Table 14-2).

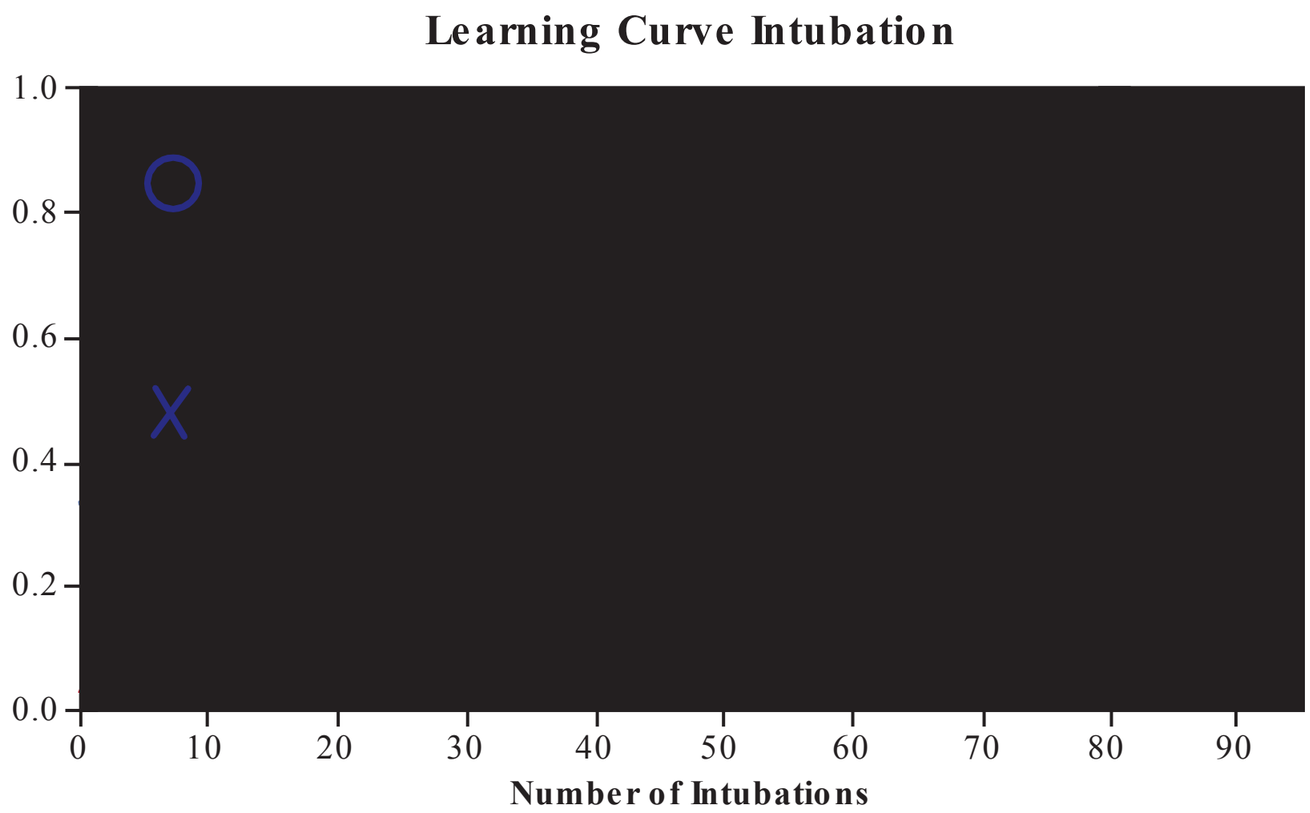


FIGURE 14-1 Intubation: conventional learning curves for intubation by DL. The solid and dashed-line curves indicate self-reported success rate for anesthesiology trainees during OR training in two centers.[2,3] Solid: Konrad et al.[2] Dashed: Mulcaster et al.[3] Low X: Novice paramedic trainee success rate in OR after conventional orientation. High X: Novice paramedic trainee success rate after similar training plus advance viewing of operator-view videos.[4] Circle: Novice CCM fellows after advance video of operator view and cadaver lab.[5]

Table 14-1

Factors that Favor Accelerated Training in BMV and DL

Fewer cases:

- Fewer intubations due to increased use of supralaryngeal devices.
- Emphasis on rapid postoperative recovery.
- Increasing availability of sophisticated alternatives to DL and interest to test or acquire skill with them leave fewer predictably difficult cases to learn advanced DL techniques.
- Concern for patients' rights and need for informed consent.

Increased need and increased acuity:

- Diffusion of demand to nonanesthesiology-based training: Training programs for EM, CCM, pulmonary medicine, hospitalist practice, and emergency medical technicians are preparing trainees for airway management, often in patients better-served by an advanced than beginner approach due to nonfasting and physiologically unstable status.[7–10] Typically, these trainees are provided airway experience in the OR, but the number is limited and usually difficult cases selected out.
- Increase in patient acuity: Spread of intensive care facilities throughout large hospital complexes and increased acuity of hospitalized patients increase the likelihood of emergent events distant from the OR.
- Decrease in availability of expert anesthesiologists: Increase in clinical intensity has reduced the ability of anesthesiologists to respond to codes outside the OR.
- Advanced training in and preparation for techniques shown effective in difficult cases may improve performance in predicted and unpredicted difficult scheduled OR cases.

Table 14-2

Factors that Weigh against Acquisition of New DL Techniques

- Low failure rate in the OR and routine ability to sustain gas exchange without perceived morbidity may diminish motivation to improve.
- Exploration of new methods not required for the case at hand is opposed by concern with short-term efficiency.
- The objective to maximize glottic exposure inherently opposes conventional ideologies of independent function and successful intubation with least glottic exposure.
- Techniques found helpful may be considered alternatives rather than means to a higher success rate.
- Some techniques seem contrary to conventional teaching and clinical impression—especially maximal flexion and thoracic flexion.

Table 14-2

Factors that Weigh against Acquisition of New DL Techniques

- Measurement tools assess the effect of specific techniques in an individual case and across cases are not in common use. For example, POGO is more useful than Cormack-Lehane (CL) grades 1-2, and detailed descriptions of epiglottis exposure are more useful than CL grade 3. Also, frequent assessment of effective compliance (isolation of force required to displace the tongue from the force required to lift the head) informs the effect of maneuvers, for example, the effect of head elevation to achieve a given POGO.
- Acceptance of the monocular field as a fixed limitation may contribute to underutilization of tools that enable shared internal view. (For contrast, see Advance review, Blade-based view).
- The infrequency of difficult intubations for experienced practitioners in the OR converts the inherent common skill indicator from a clinical outcome (success rate) to a technical ability (to intubate with least glottic exposure). Frequency of two or more attempts, or statement of best POGO obtained, would be more relevant to skill with difficult or emergent cases.
- Lack of structure to assure achievement of complete skill set: The acquisition of each skill could inhibit additional skill acquisition unless training ensures development of each. For example, novices who experience the value of ELM may be less likely to become facile with independent elevation and manipulation of the head and neck, and vice versa, or, to integrate both techniques.
- Lack of orientation to simulate situations that require specific skill sets. Techniques to address difficult DL are more likely to be considered "tricks" than required skills, and skills in BMV are simply presumed to require months of OR experience **(ref).**

Abbreviation: ELM, external laryngeal manipulation; POGO, percent of glottic opening.

SPECIFIC TRAINING PROGRAM CONCEPTS AND TECHNIQUES

Just as skilled practitioners continue to simulate epiglottis-only exposure in preparation for unpredicted difficult cases,[11,12] there are multiple techniques that novices can routinely employ to improve reliability of glottic exposure (Table 14-3). Those same techniques are applicable when well-experienced practitioners encounter unexpected difficulty, or patient circumstances make first pass success especially desirable. This focus both on patients at risk and operators with minimal experience encourages separate practice of each potentially valuable skill, and then practice in integrated application of those skills. The end-product should be a smooth integration of techniques and advanced maneuvers that facilitates rapid exposure with minimal force and optimal controlling less than 20 seconds, until exposure is optimal, then precise atraumatic ET placement.

CREDULITY OF FLEXION-FACILITATION OF DL

Although practical studies consistently support maximal head elevation to facilitate glottic exposure, conventional concepts and clinical impressions that favor extension may cause cognitive dissonance. Visualizing flexion-facilitation by comparison of X-rays, palpation, and direct observation (See Anatomy Chapter 1) is helpful. However, experiential exercises convey the reality of flexion-facilitation most effectively.

Reproducing Levitan's demonstration is helpful[4]. After a curved or straight blade is positioned to optimally expose the glottis, routinely the percent of glottic opening (POGO) can be directly observed to increase from less than 50%to near 100% as the head is lifted from flat on the table, and POGO does not decrease as head elevation is continued to maximal. In fresh unpreserved cadavers, the POGO continues to improve or remains high as rotation forward is continued until the vector on the handle is toward the feet. In this position, the trachea is vertical, as is the ET during insertion. A blade-based optical system (C-Mac, KARL STORZ Gmbh & Co. KG or Glidescope Direct Intubation Trainer, Verathon Inc., Bothell, WA—see Chapter 24) can be useful to assure stable positioning of the blade relative to the glottis during this head movement exercise.

Two clinical impressions that weigh against flexion should be considered. First, in some cases it is apparent that thoracic spine flexion should precede cervical spine flexion. For example, in obese patients and in many with a short or thick neck, cervical flexion rotates the chin and anterior neck toward the upper chest and impairs DL by decreasing submandibular effective compliance. Impingement of tissue is avoided when thoracic flexion

Table 14-3

Concepts (Re)Discovered to Improve DL Success in Difficult Cases, and Techniques and Comments

Advance Learning of the Operator View

Study of the authentic operator view doubled novices' initial success rate[13] (Fig. 14-1).

Shared Viewing

A blade-based view transmitted to a bedside or device-based screen enables the trainee and the instructor access to the effects of the other's manipulations. Alternating between blade-based and direct viewing is useful to convey the value of ELM in stabilizing the tongue during blade insertion.

Communicating the "epi flip" is far easier when viewed by instructor and trainee. Comparison of the blade view of blade tip position relative to the hyoepi glottic ligament and the corresponding DL view of the epiglottis response to "pulsed" tip pressure is highly instructive of how to position the blade in DL.

Instructor confirmation via blade-based view of the trainee controlling the epiglottis before attempting glottic exposure is important to avoid bypass of the epiglottis, as is tempting in easy cases.

The blade-based view also facilitates an assistant's fine-tuning glottic exposure by his/her external laryngeal manipulation.

Rapid Acquisition of Optimal Glottic Exposure

Because the most difficult cases may require maximal (thoracic as well as cervical) flexion, advance considerations inlcude lower table, shoulder roll or ramp construction, and voice control of assistants to enable routine use of external laryngeal manipulation (ELM).

Routine Use of ELM

Employment of ELM early in training may help convert the trainee's approach to laryngoscopy from "probing with a stick" to a more dynamic exploration.

Glottic Exposure Optimal Rather than Adequate

Axial manipulation is routinely employed simultaneously with ELM until further improvement in glottic exposure cannot be made.

Precise Control of Delicate Tissue

Fine left-hand motor control is enabled when lifting force is assumed by the assistant's or the operator's right hand.

Bimanual manipulation converts probe with a stick to multilateral exploration.

The "epi flip" defines optimal position of curved blade tip.

Maintain Orientation

The priority is to find and control, not circumvent, the epiglottis.

Bimanual manipulation can facilitate tongue control and early sighting and tracking of the epiglottis.

Evaluate Effect of Manipulations

The value of ongoing axial and ELM manipulations is informed by tracking effective compliance of the submandibular space: by frequent gentle blade lift to assess how much of the epiglottis or glottis (percent of glottic opening, or POGO) can be seen.

Incorporate Simulation of Difficult Cases into Routine Practice

Practice shifting the angle of approach toward the right corner of the mouth with the curved as well as the straight blade to become familiar with blade-dentition interaction as well as altered view of landmarks.

Isolated Skill Practice

Isolation of skill practice fosters more complete development. For example, rapid initial axial positioning with support provided by an assistant removes force required to lift the head from that required to displace the tongue. Then precise techniques such as the epi flip and ELM can be explored with a light touch.

Smooth Integration of Multiple Techniques

Facility with basic techniques makes most intubations straightforward. That the next case may be the most difficult ever encountered encourages continued application and integration of every technique.

Team Practice/Advance Instruction of Assistants

Inevitability of unpredicted crisis combined with the need to call on naïve passersby requires that concise clear instruction be worked out and practiced in advance.

displaces the head forward relative to the chest (Figs. 5-2, 5-3, 5-4 and 5-6). On this basis, thoracic spine flexion may be an important benefit from building a ramp for airway care of morbidly obese patients. Other observations valuing thoracic spine flexion are summarized in Chapter 1.

A second clinical impression that opposes flexion is how inability to lift the tongue in difficult DL is interpreted. Often the mechanism is perceived "an anterior larynx," and the idea of flexion seems like lifting your head when you can't see under something. This bias seems to derive from the three axes alignment theory, which orients to aligning the posterior airway structures, and so opposes flexion. We suggest impairment of soft tissue displacement forward is due primarily to tension in the SHL suspension cable, which is relieved by flexion in the low cervical and thoracic spine, and impingement of anterior tissue spaces, which spaces are separated by thoracic flexion (Fig. 5-4).

We are aware of only two observations of axial manipulation in difficult DL that did not conclude in favor of flexion. First, Chevalier Jackson[14,15] recommended extension just a few years after DL in humans was first described; later he fully reversed his recommendation, emphasizing that if the head was held high enough, even a-o extension could be unnecessary. Second, a single center MRI study concluded that axis alignment with moderate flexion (7 cm head elevation) was not different from head flat on the table.[16] The images appear to show cervical spine curvatures different from those we would consider typical for these positions.

BAG-MASK-VENTILATION

By conventional training, effective bag and mask skills require months of OR experience. The Critical Care Medicine Multidisciplinary Training Program at the University of Pittsburgh provides airway-novice fellows a foundation of bag-mask-ventilation (BMV) skills within a few lab sessions over several days.

"Feel of the Bag"

The anesthesiologist with a hand on the soft latex bag in a low-resistance breathing system learns to become quite sensitive to subtle changes in pattern such as due to patient effort, airway trapping, and upper airway obstruction. During open thoracotomy in the OR (or in non-preserved cadavers laboratory), direct observation of hand pressure recruitment of sub pleural and segmental atelectasis is also highly informative.

Because self-inflating resuscitation bags in the Baltimore Shock-Trauma ICU provided less sensitivity, Dr. Crawford McAslan used inflated latex bags from the OR to recruit atelectasis in ICU patients (JVS, personal communication). Subsequently it was observed that sensory feedback from a self-inflating bag was enhanced by in-flexing, which is required to deliver manual continuous positive airway pressure (CPAP). "Bagging by feel" applying CPAP via bedside resuscitation bags is taught routinely at the University of Pittsburgh CCM Training Program.

Trainee ability to sense and synchronize assistance by feel allows their visual attention elsewhere during a code. Within two breaths of a decrease in compliance they should be able to differentiate the cause as inspiratory obstruction, a soft palate flap valve, air trapping, or reduced thoracic wall compliance. Most manikins constructed to teach resuscitation have substantial pharyngeal leaks that prevent sensing an effective mask seal, which is the fundamental requirement to learning to bag by feel. Therefore, fellows acquire bag-sense skills and are tested in a jury-rigged system where spontaneous breathing is simulated by pulling open a QuickLung (by IngMarMedical) or Standard (TTL bellows). Then bag-sense is tested in spontaneously breathing cadavers as below. (We have not yet made this teaching structure exportable, so many practitioners are unaware of such skills and still believe "anyone can bag.")

Airway and Mask Technique

As in DL, early concentration on advanced mask and airway techniques has been helpful for trainees who encounter difficult airways early in the course of their fellowship. Concern about occult hypoxia in code situations sets our bias to apply a two-hand jaw thrust to open the airway when applying the mask, and low-pressure assisted ventilation with BIPAP. The trainee may back off to less aggressive techniques as continued airway patency and effective mask seal justifies. Training in advanced mask and airway techniques requires realistic anatomic and tissue character variations (prominent nose, hollow cheeks, flaccid tongue, flap valve soft palate, subluxing jaw) that have not yet been simulated from tissue surrogates. Advanced airway training is provided by simulating spontaneous ventilation in unpreserved cadavers, by transmission of bellows-generated negative pressure via endobronchial tubes inserted retrograde via thoracotomy.

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CHAPTER 15

Examples and Illustrations of Conditions Predisposing to Difficult Airway Management

Samer Melhem and Mario Montoya

ANATOMIC ABNORMALITIES

Limited Mouth Opening

Limitations in mouth opening impede the ability of the laryngoscopist to visualize pharyngeal or laryngeal structures. Ideally, mouth opening should exceed 6 cm or 3 fingerbreadths (Fig. 15-1).

Disproportionally Large Tongue

Direct laryngoscopy requires that the tongue be forced into the floor of the mouth to permit the laryngoscopist to view the glottis. The larger the tongue, the more difficult this becomes, contributing to poor laryngoscopy grades. The disproportionally large tongue is usually evident when the Mallampati class is evaluated (Fig. 15-2).

Dental Abnormalities

Large, protruding teeth, or teeth lying at odd angles may complicate attempts to place the laryngoscope in the mouth, visualize the laryngeal orifice, or place an endotracheal tube (ETT). They may also be at higher risk for tooth damage during direct laryngoscopy, as well as ETT cuff damage during intubation (Figs. 15-3 and 15-4).

Abnormal Neck Size or Mobility

Patients with short, thick necks may present difficulty in achieving normal extension and frequently have worse laryngoscopy grades at direct laryngoscopy than patients with long, thin necks. Positioning in these patients can greatly improve laryngoscopy success (Fig. 15-5).

Mandibular Size

A small mandible, or receding chin, adversely affects the ability to visualize the glottis making the grade of laryngoscopy worse (Fig. 15-6).

Epiglottis

Occasionally, the elongated epiglottis is difficult to elevate sufficiently with the curved blade, and a straight blade must be used to lift it directly out of the way (Fig. 15-7).

Nasal Turbinates

Prominent or protuberant nasal turbinates may create an obstruction to passage of nasopharyngeal airways or nasal ETTs leading to trauma and epistaxis, which can be severe, especially if the patient is in an anticoagulated state (Fig. 15-8).

Facial Hair

Bushy beards or goatees may complicate attempts to make a face mask seal, resulting in difficult mask ventilation (Fig. 15-9).

CONGENITAL ANOMALIES

Many congenital anomalies affecting facial, oral, pharyngeal, or cervical structures create challenging intubating conditions.

Oral Cavity

Some congenital abnormalities result in enlargement of the tongue (macroglossia). This is commonly seen in Down syndrome, Beckwith-Wiedmann syndrome, as well as other chromosomal abnormalities. Macroglossia can also be seen with mucopolysaccharidosis, hypothyroidism, alpha-mannosidosis and aspartylglucosaminidase deficiency (Fig. 15-10).

Larynx

Airway stenosis may be a congenital condition, or may be associated with prolonged intubation, making passing an ETT difficult (Fig. 15-11).

Cervical Spine

Cervical spine skeletal anomalies may complicate attempts to manage the airway by conventional means, due to either decreased range of motion (making axis alignment difficult), or to ligamentous instability (Fig. 15-12).



FIGURE 15-1 Limited mouth opening.



FIGURE 15-2 A disproportionally large tongue.

(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.).



FIGURE 15-3 Large, protuberant incisor teeth.



FIGURE 15-4 Severe dental malocclusion. (From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

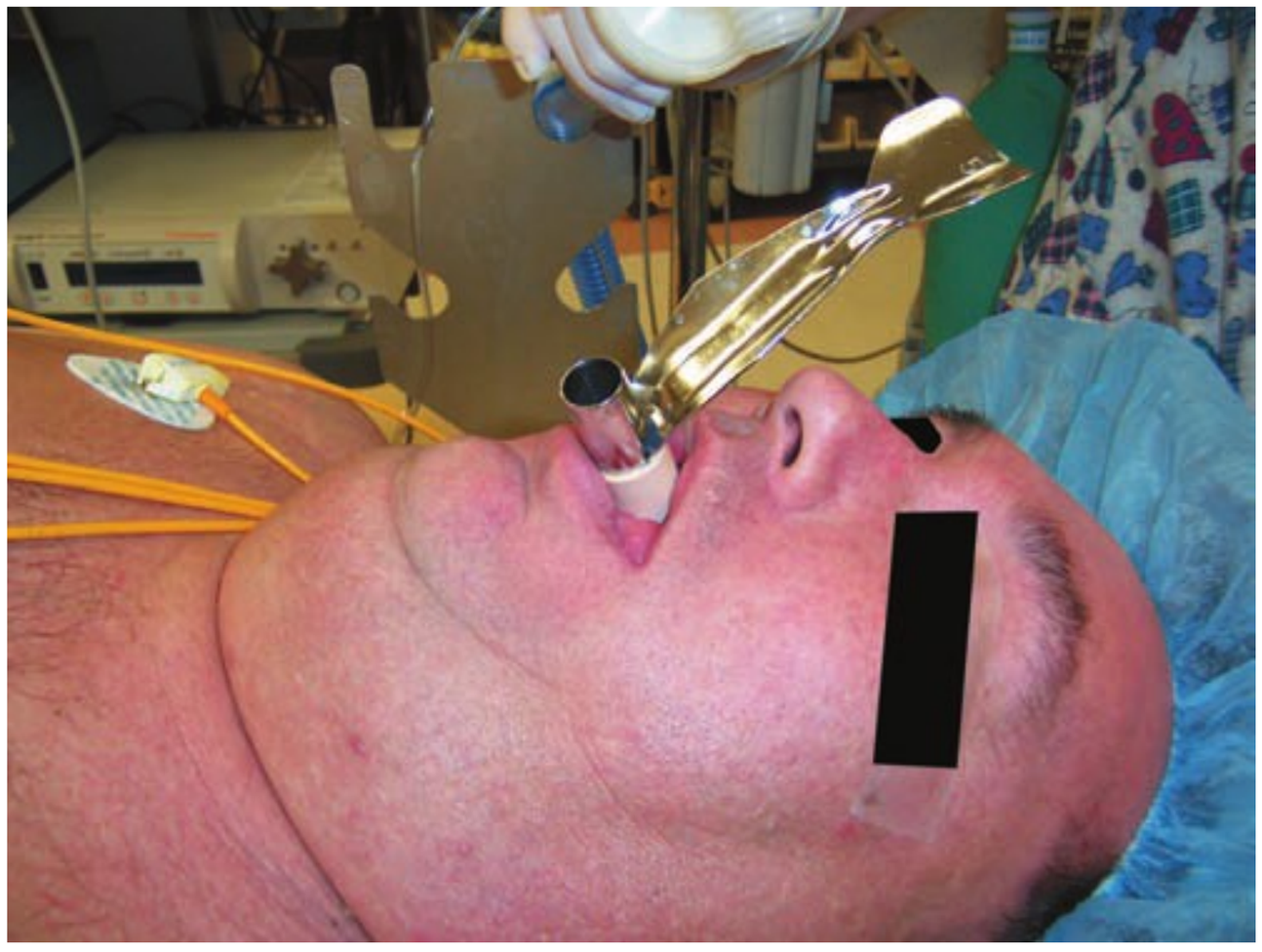


FIGURE 15-5 Short thick neck: a grade 3 laryngoscopy was present in this patient.



FIGURE 15-6 Short mandible with overbite.

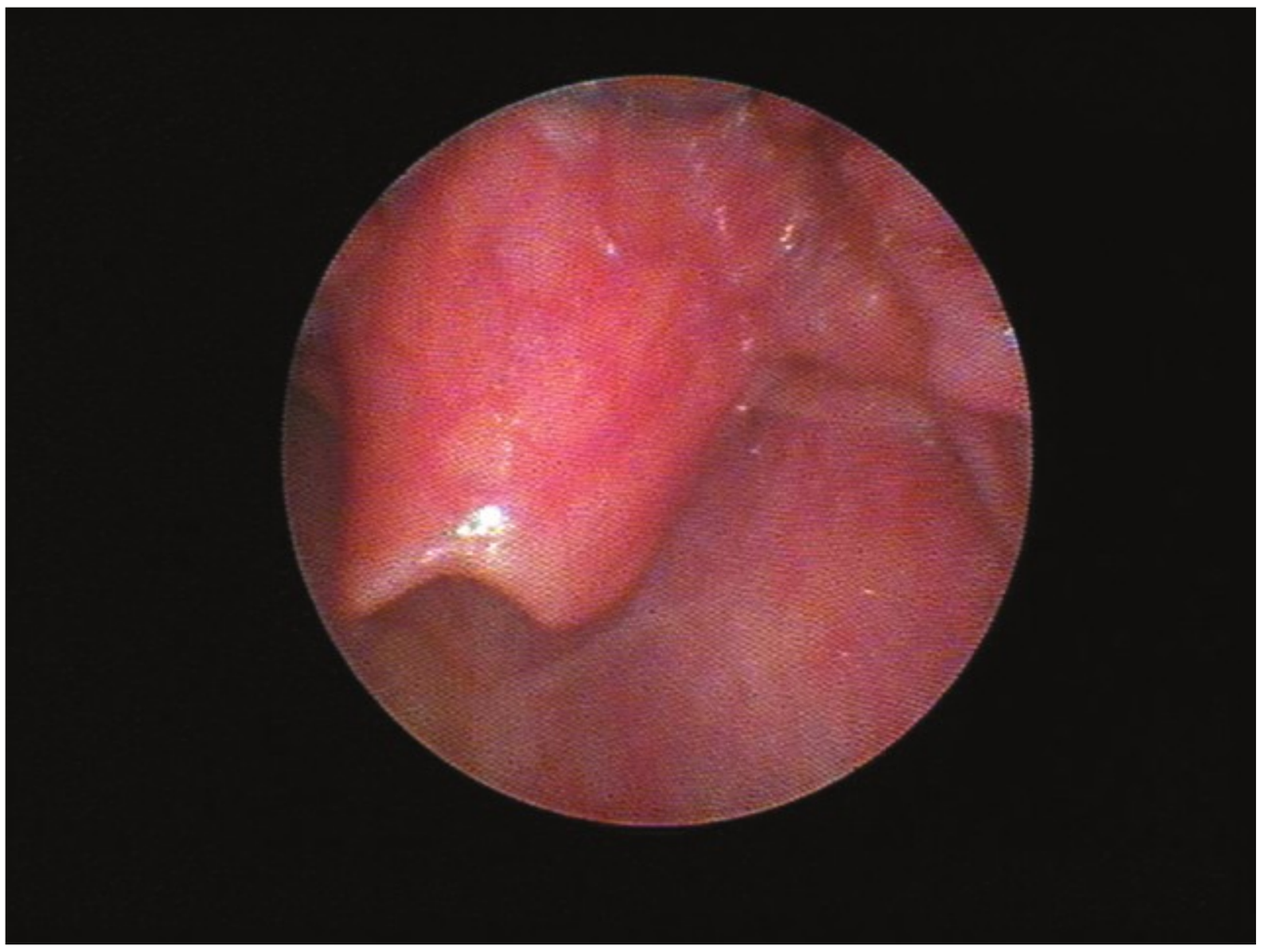


FIGURE 15-7 Long, floppy epiglottis.

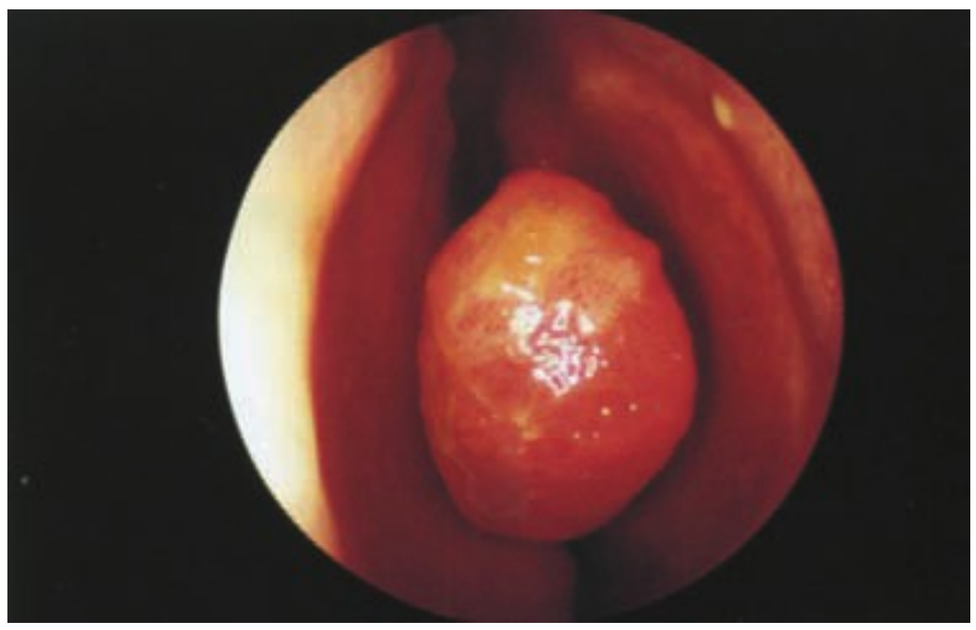


FIGURE 15-8 Prominent nasal turbinate. (From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)



FIGURE 15-9 This beard resulted in poor mask ventilation.



FIGURE 15-10 Enlarged tongue in Down syndrome.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)



FIGURE 15-11 Congenital subglottic stenosis.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

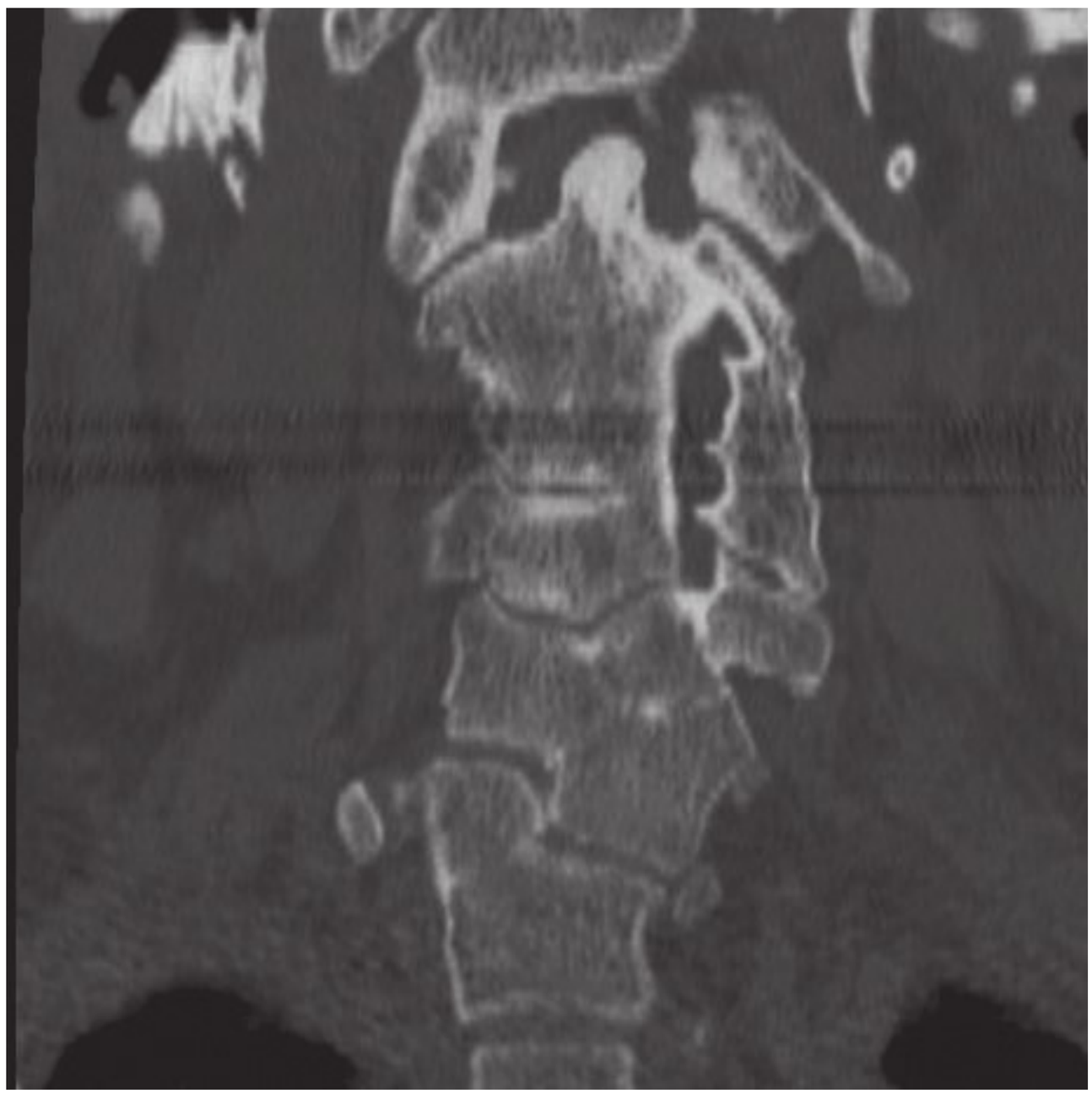


FIGURE 15-12 Severe cervical spine anomaly in Klippel-Feil syndrome.
(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

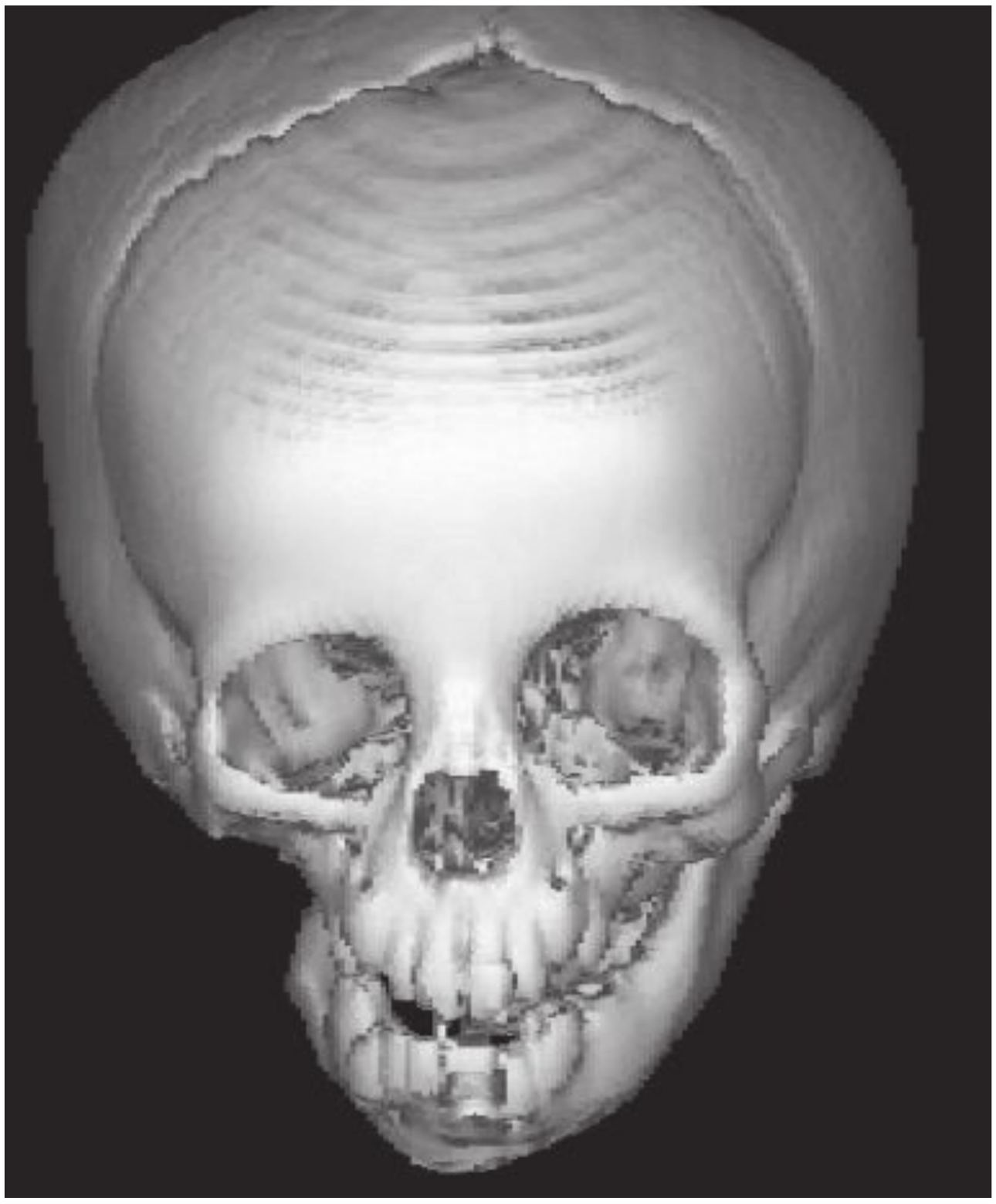


FIGURE 15-13 Congenital facial malformation evident on 3-D CT scan.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)



FIGURE 15-14 Congenital subglottic hemangioma which mandated tracheostomy in this infant.

(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

Facial Skeleton

Abnormalities of the maxilla or mandible can complicate face mask ventilation and direct laryngoscopy in diseases such as Pierre Robin syndrome, where the mandible is abnormally small (micrognathia) (Fig. 15-13).

Neck

Large congenital malformations may compromise the airway, necessitating tracheostomy (Fig. 15-14).

PATHOLOGY

Many diseases of the head, neck, and chest can adversely affect direct laryngoscopy.

INFECTION

Epiglottitis

Infection of the epiglottis and supraglottic region can create life-threatening airway obstruction.

In epiglottitis, often caused by *Haemophilus influenzae* type b in children, severe supraglottic edema and erythema may lead to airway obstruction. This mandates securing of the airway by endotracheal intubation via direct laryngoscopy or by surgical means if necessary (Fig. 15-15A). A lateral soft tissue cervical radiograph usually reveals the "thumb sign" of an enlarged, inflamed epiglottis (Fig. 15-15B).

Ludwig Angina

Infection of the floor of the mouth, usually an extension of dental infection ("trench mouth"), can cause severe pain on swallowing, trismus, and difficulty opening the mouth and displacing the tongue during direct laryngoscopy. Figure 15-16A shows a patient with swelling and erythema of the submandibular space, a manifestation of Ludwig angina. Figure 15-16B shows a CT of a patient with Ludwig angina. Note the extent of swelling and potential airway compromise.

Retropharyngeal Abscess

This process, most common in young children, causes neck stiffness and bulging of the posterior pharyngeal wall. In Fig. 15-17, a CT of a patient with retropharyngeal abscess shows marked prevertebral edema and narrowing of the upper airway.

Dental Abscess

Large abscesses may lead to trismus and distortion of intra-oral structures. Figure 15-18 shows a patient with a dental abscess and significant jaw swelling and is likely to have trismus.

Peritonsillar Abscess

An abscess in the tonsillar fossa often results in drooling, trismus, odynophagia, and bulging of the soft palate of the affected side. Figure 15-19 depicts a peritonsillar abscess with bulging soft palate and copious exudate.

NEOPLASMS

Supraglottic Cancer

Carcinoma of the pre-epiglottic space, shown in Fig. 15-20, makes direct laryngoscopy difficult, particularly with a curved blade.

Laryngeal Carcinoma

Carcinomas of the larynx may be relatively silent until they have progressed to significant airway obstruction (Fig. 15-21).

Nasopharyngeal Carcinoma

Like other airway tumors, nasopharyngeal carcinoma may become extensive before discovery. In the MRI shown in Fig. 15-22, widespread involvement of the nasopharynx is evident.

TRAUMA

Mandibular Fracture

Mandibular fracture usually results in trismus, edema, and distortion of intra-oral structures. This may make direct laryngoscopy and intubation by the oral route difficult. Figure 15-23A shows a CT scan of a severe, comminuted mandibular fracture. The supporting ring of the mandible is lost, resulting in a "flail mandible." Figure 15-23B depicts the surgical repair of the comminuted fracture shown in Fig. 15-23A.

Facial Fractures

Bleeding, edema, loss of anatomic landmarks, and airway obstruction combine to make management of the airway very challenging in these patients. If the airway is inaccessible or unrecognizable, surgical airway is necessary (Fig. 15-24).

Cervical Spine Fracture/Dislocation

Recognized or potential cervical spine injury mandates extreme care with airway management. Cervical spine flexion or extension may result in spinal cord injury. In-line cervical immobilization is typically used in the trauma patient with potential spine injury who requires intubation for airway control. Patients with known cervical spine injury are managed with fiberoptic flexible or rigid optical scopes, or other forms of intubation that require no significant motion of the cervical spine (Fig. 15-25).

Laryngeal Injury

Blunt injury to the larynx may result in fractures of the cartilages or disruption of the airway. Airway management attempts with direct laryngoscopy may fail or worsen the injury. Figure 15-26 shows a laryngeal fracture. Disruption of the laryngeal cartilages is evident in this CT of the larynx. Tracheostomy may be necessary in such patients, until surgical repair can be undertaken.

EDEMA

Edema of the oral cavity, neck, larynx, or pharynx from various causes may compromise the airway and complicate attempts at face mask ventilation and direct laryngoscopy (Figs. 15-27–15-29).

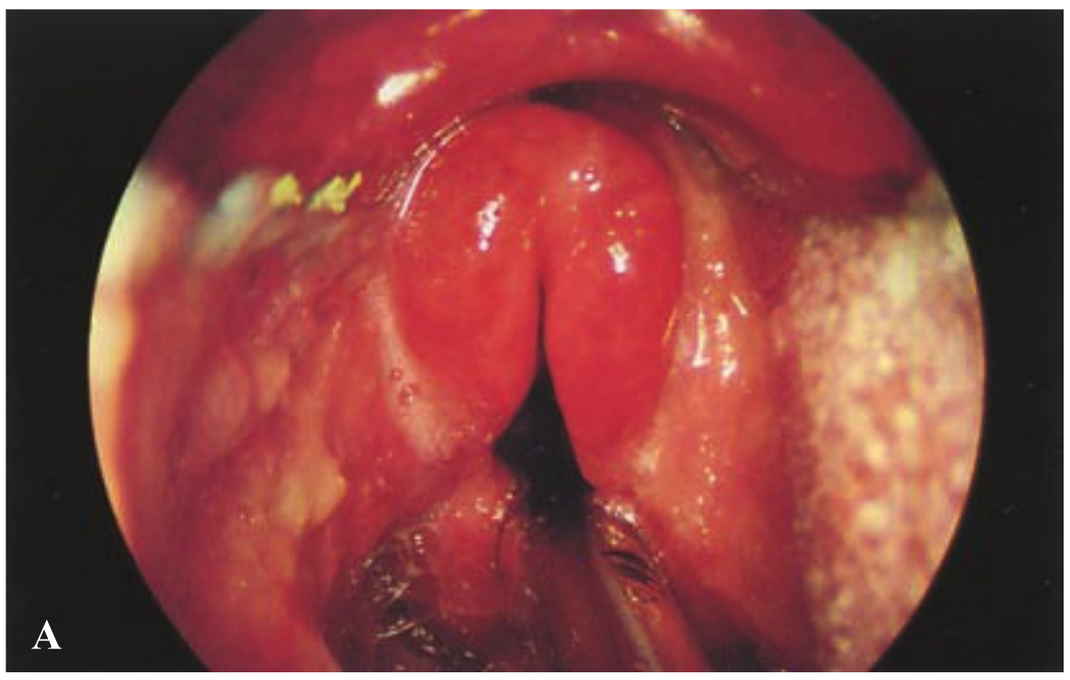


FIGURE 15-15 **A:** Severe supraglottic edema and erythema in acute epiglottitis. (From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.) **B:** Enlarged, "thumb-shaped" epiglottis evident on lateral soft-tissue cervical radiograph.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)



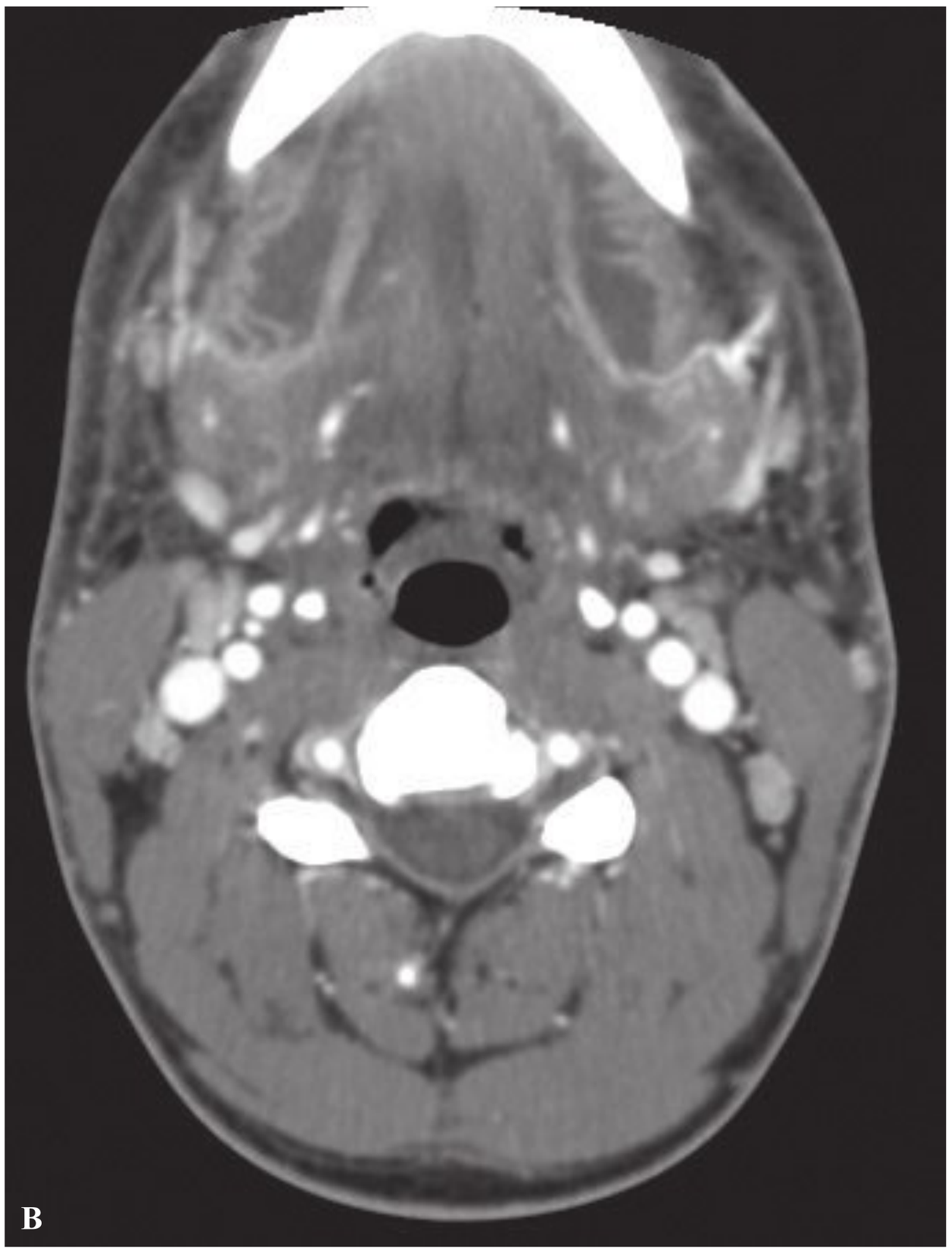


FIGURE 15-16 **A:** Swelling and erythema of the submandibular space. (From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.) **B:** CT of a patient with Ludwig angina. (Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

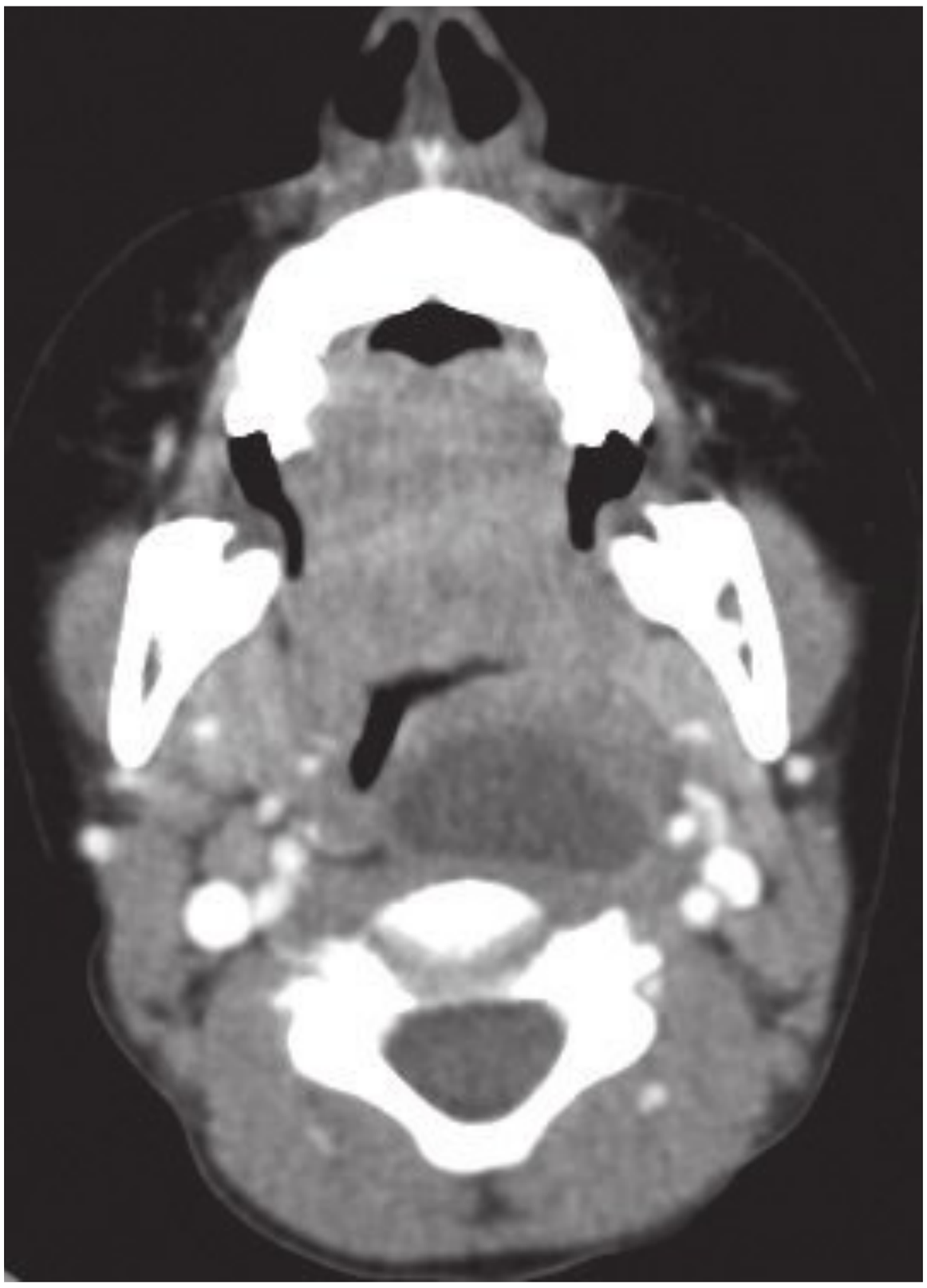


FIGURE 15-17 Retropharyngeal abscess.
(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

ARTHRITIS/BONY HYPERTROPHY

Arthritic changes of the temporomandibular joints, the atlanto-occipital joint, or the joints of the cervical spine can make direct laryngoscopy very challenging and may mandate awake intubation, depending on the degree of instability or restriction of motion (Figs. 15-30 and 15-31).

MISCELLANEOUS

Hematoma, tissue infiltration, or hypertrophy of tissues involving the airway may distort structures, restrict range of motion, or reduce the space available for viewing or placement of airway management tools (Figs. 15-32–15-34).



FIGURE 15-18 Dental abscess with significant jaw swelling.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)



FIGURE 15-19 Peritonsillar abscess.

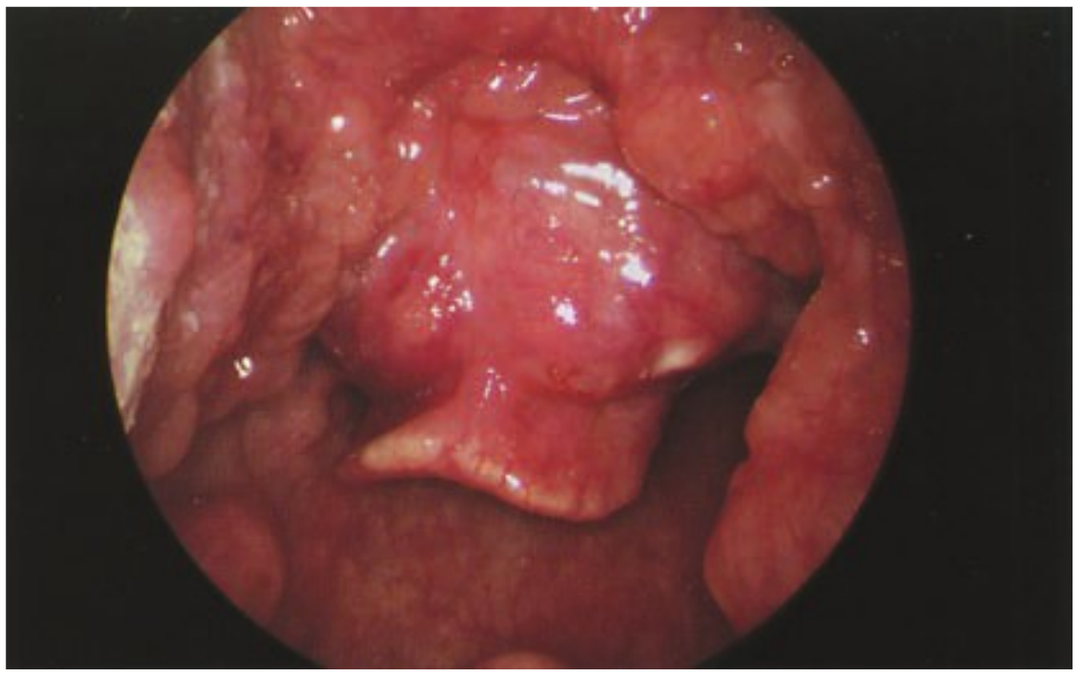


FIGURE 15-20 Carcinoma of the pre-epiglottic space.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

FIGURE 15-21 Laryngeal carcinoma.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA; JB. Lippincott Co; 1995, with permission.)

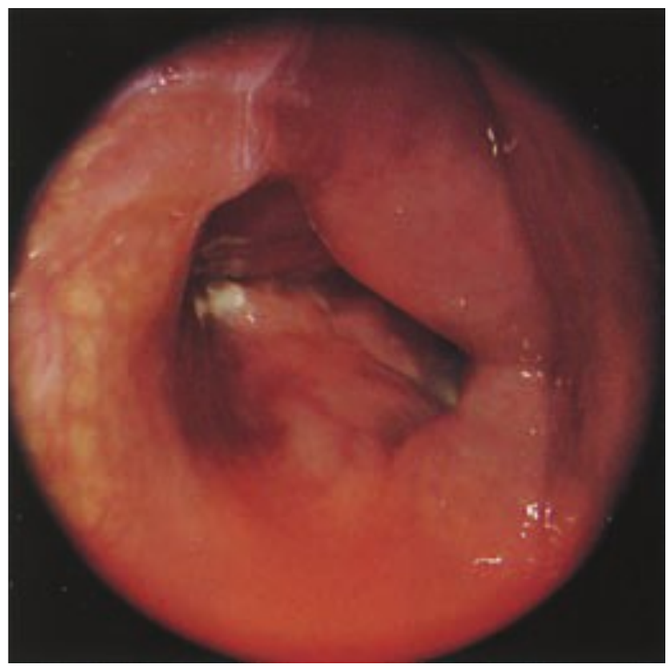
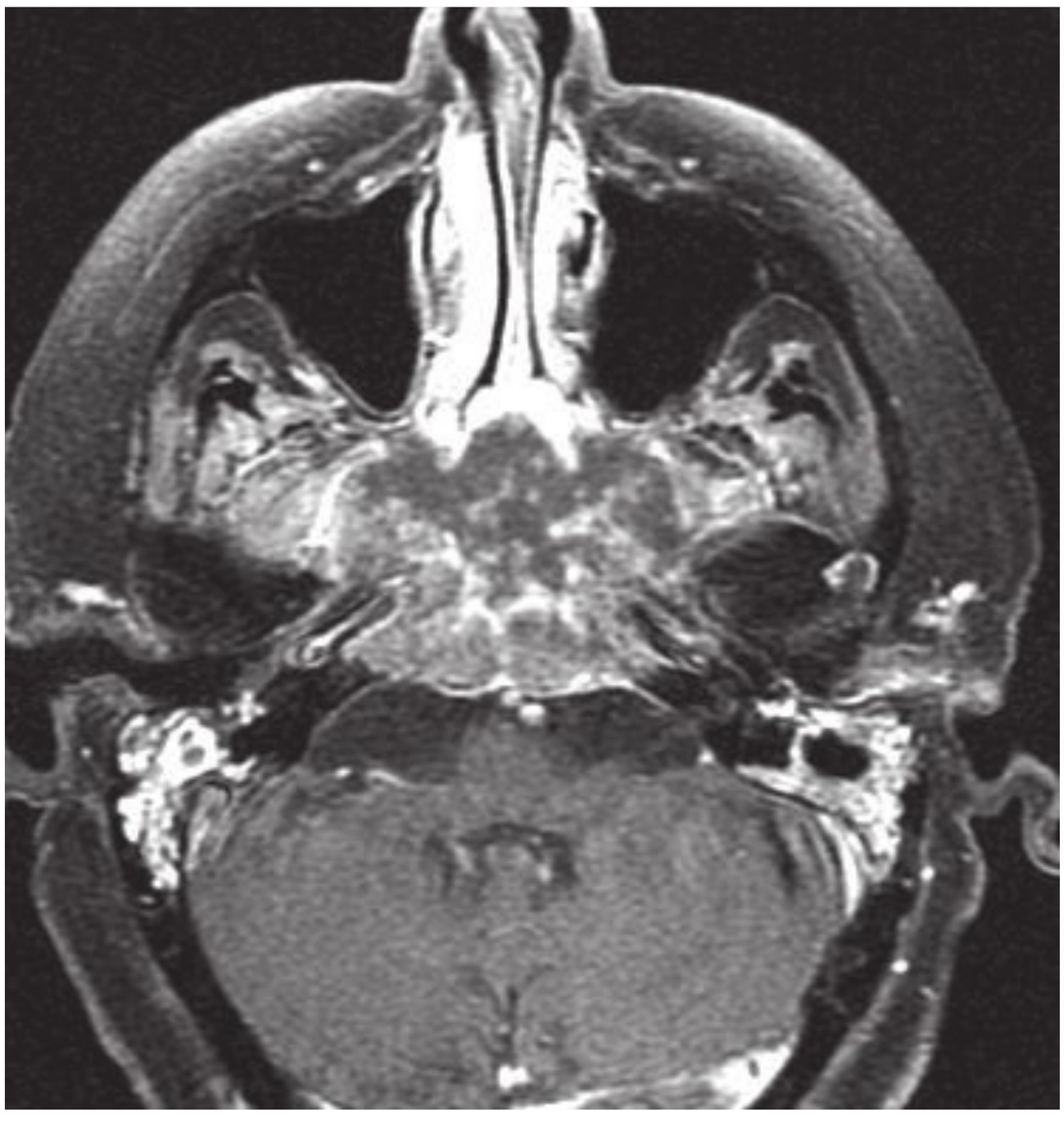


FIGURE 15-22 Nasopharyngeal carcinoma.
(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)



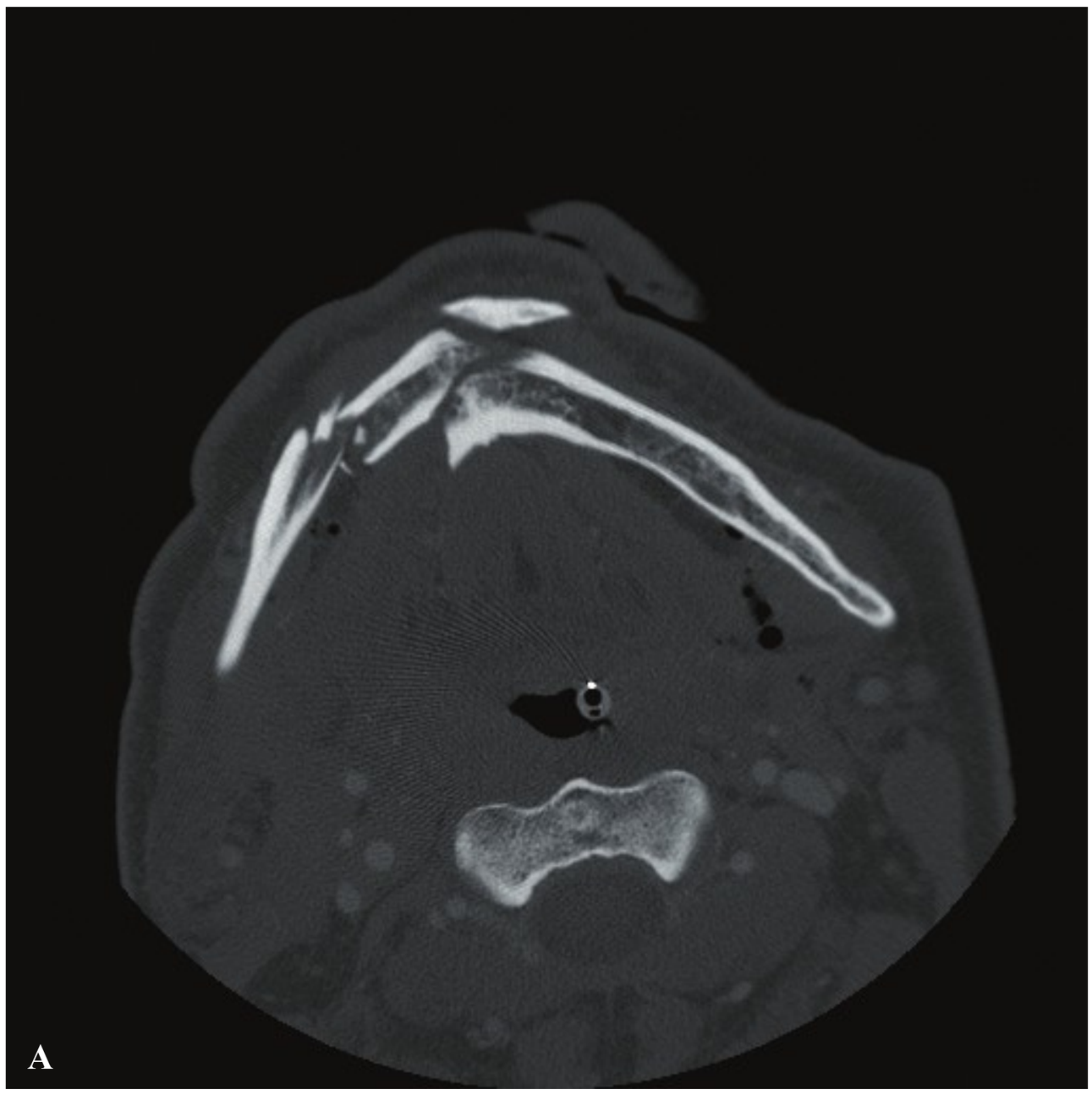




FIGURE 15-23 **A:** Severely comminuted mandibular fracture. **B:** Surgical repair of fracture pictured in Figure 15-23A. (Courtesy of Lison Yeung, DDS and Dr. William Chung, Department of Oromaxillofacial Surgery, University of Pittsburgh School of Medicine.)

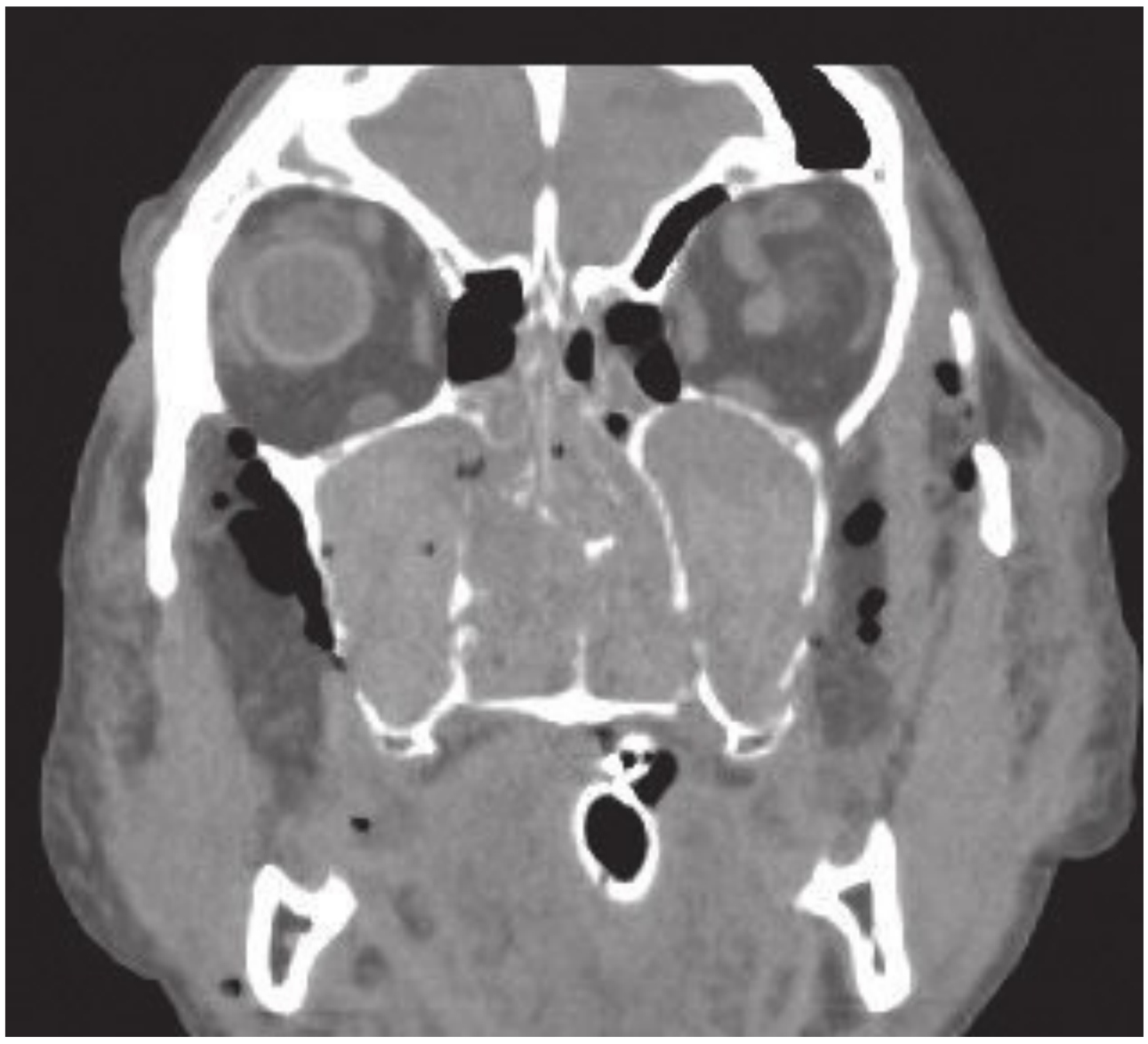


FIGURE 15-24 A LeFort I fracture of the midface. Multiple nasal fractures and maxillary sinuses filled with blood are evident on this coronal CT scan.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

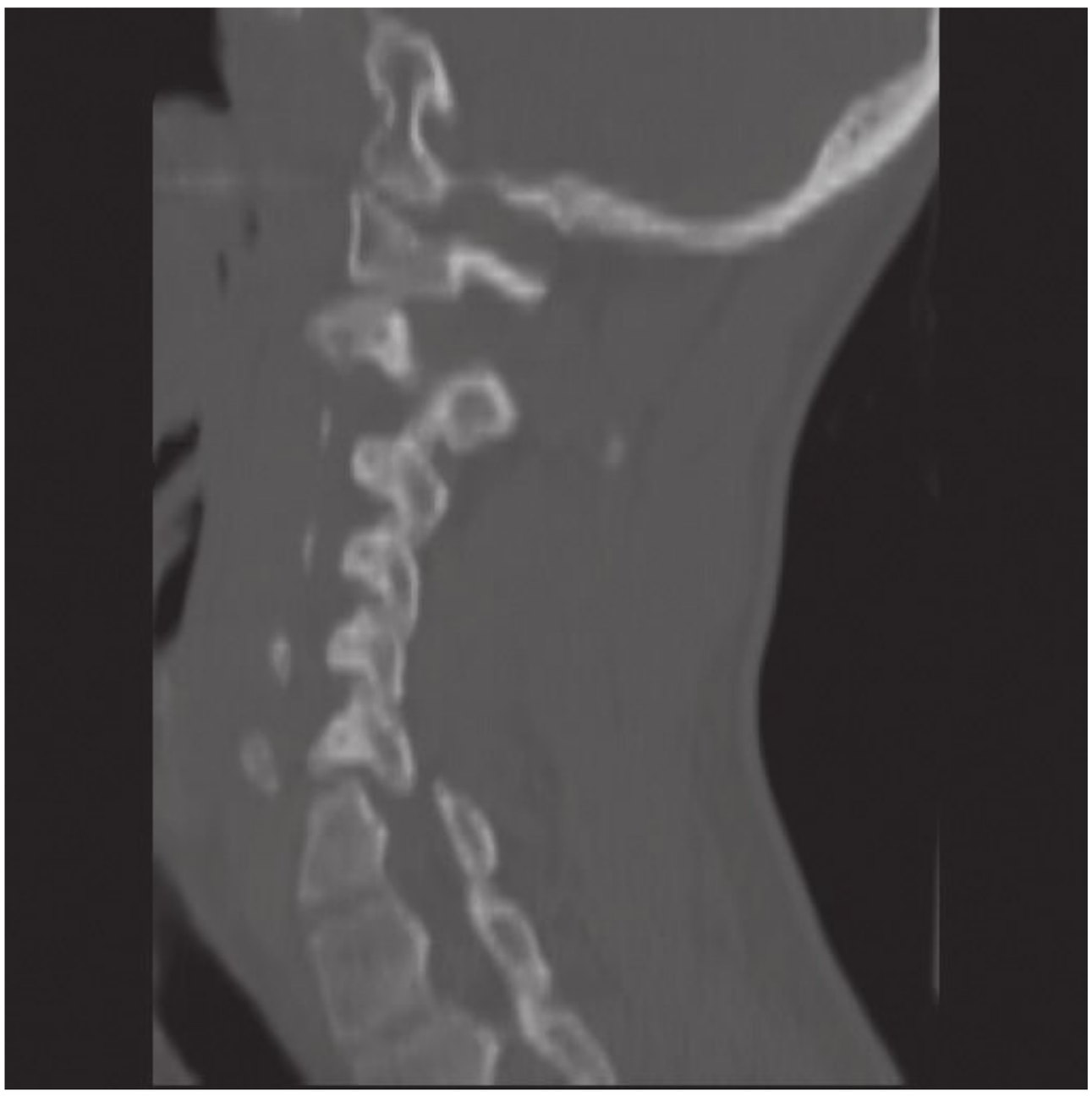


FIGURE 15-25 This tomogram shows marked anterior displacement of C6 on C7 due to bilateral facet dislocation.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)



FIGURE 15-26 Laryngeal fracture. (From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)



FIGURE 15-27 Postoperative neck edema from shoulder arthroscopy. This can become severe enough to shift the trachea and occlude the airway.

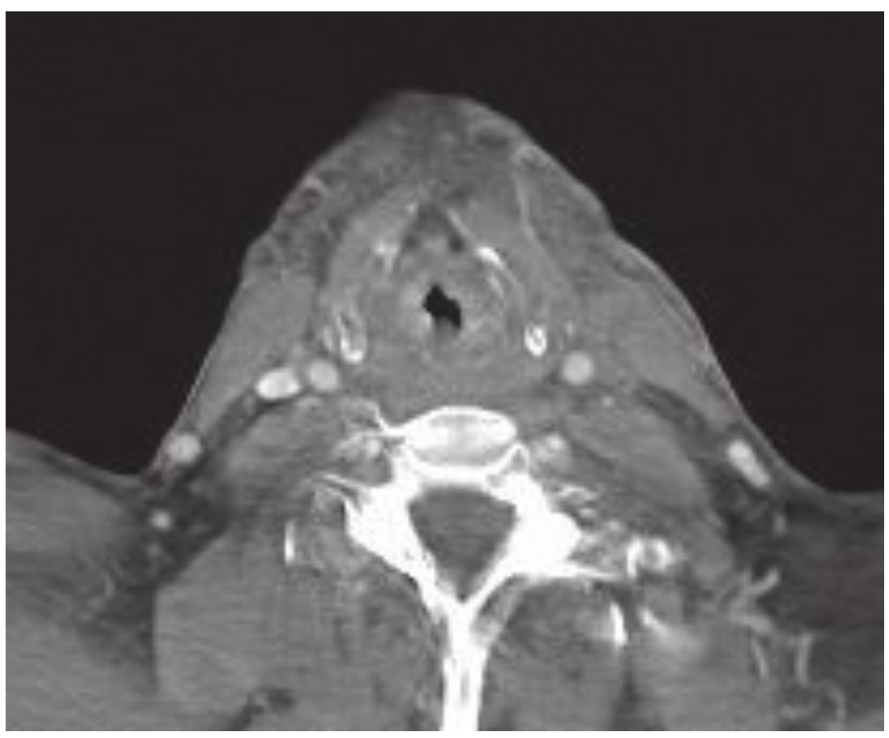


FIGURE 15-28 Generalized edema of the oral cavity, pharynx, and airway from radiation is evident in this CT scan.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

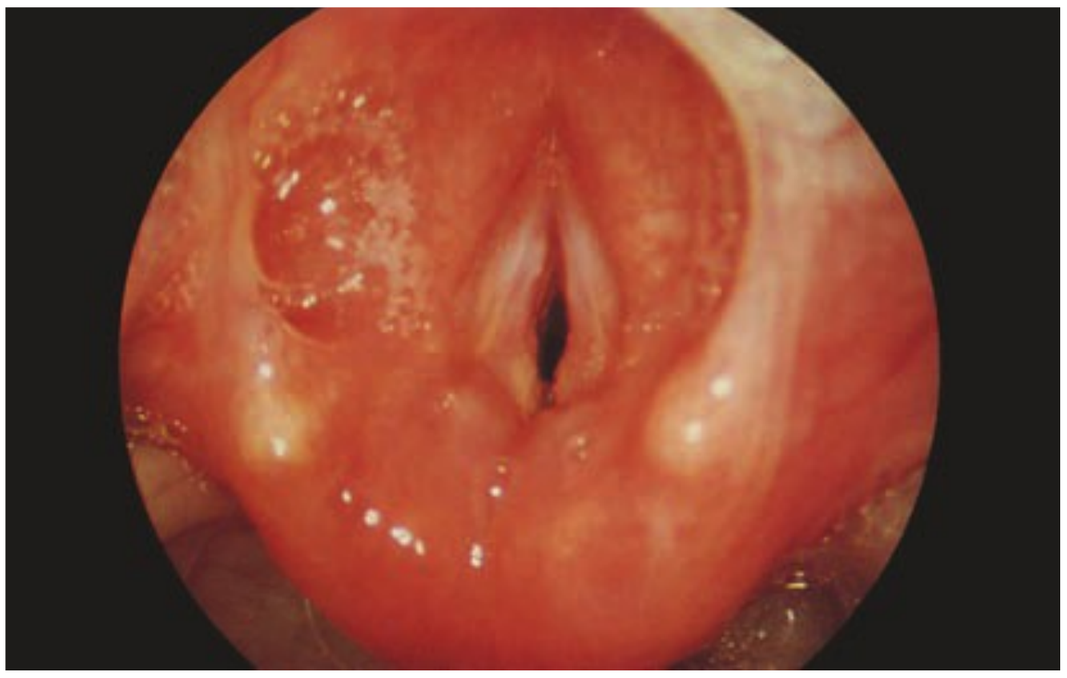


FIGURE 15-29 Viral laryngotracheobronchitis frequently causes significant upper airway edema, resulting in inspiratory stridor.

(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

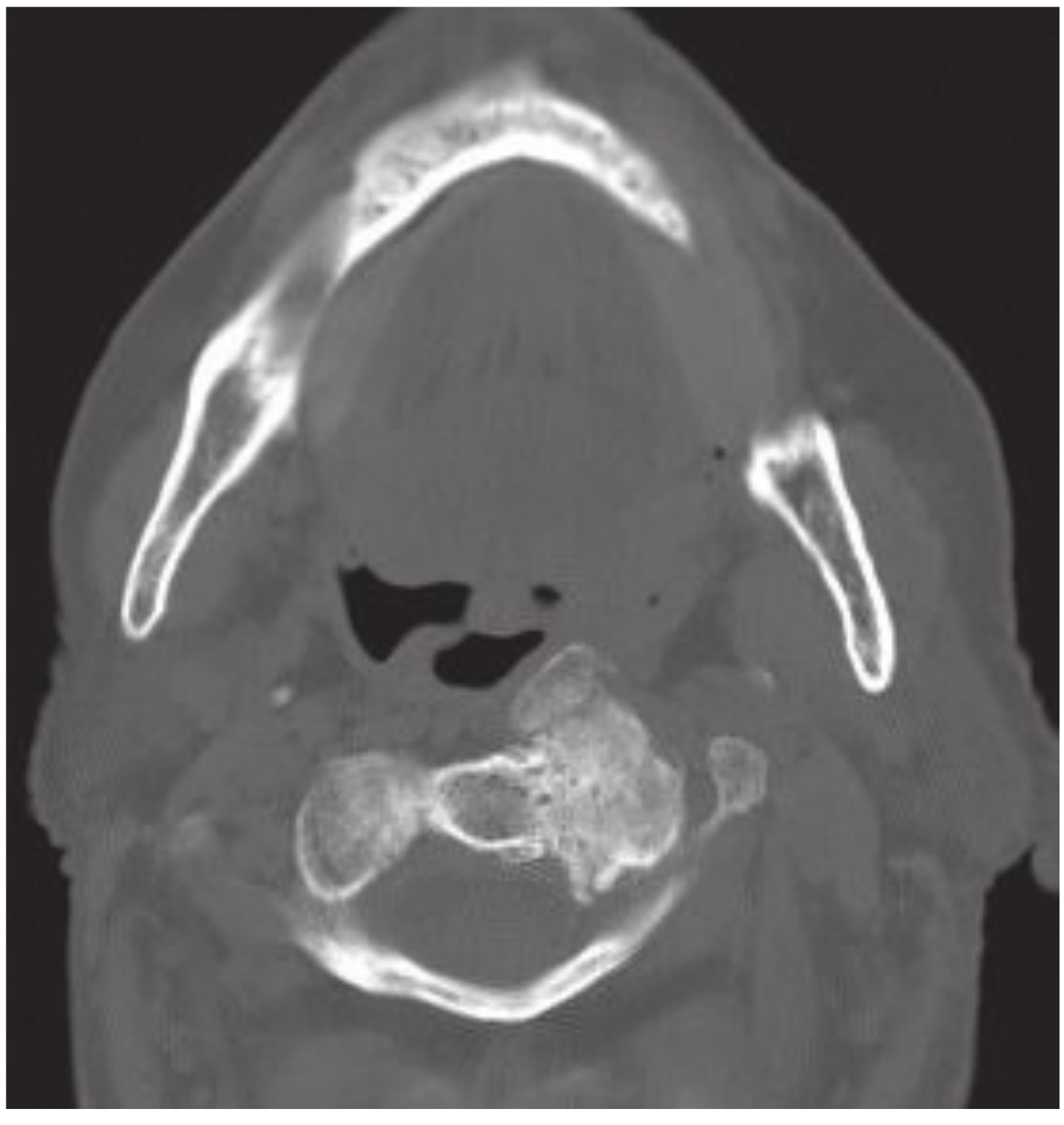


FIGURE 15-30 CT scan reveals osteoarthritis of the cervical spine with large osteophyte at C2, protruding into the posterior pharynx.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

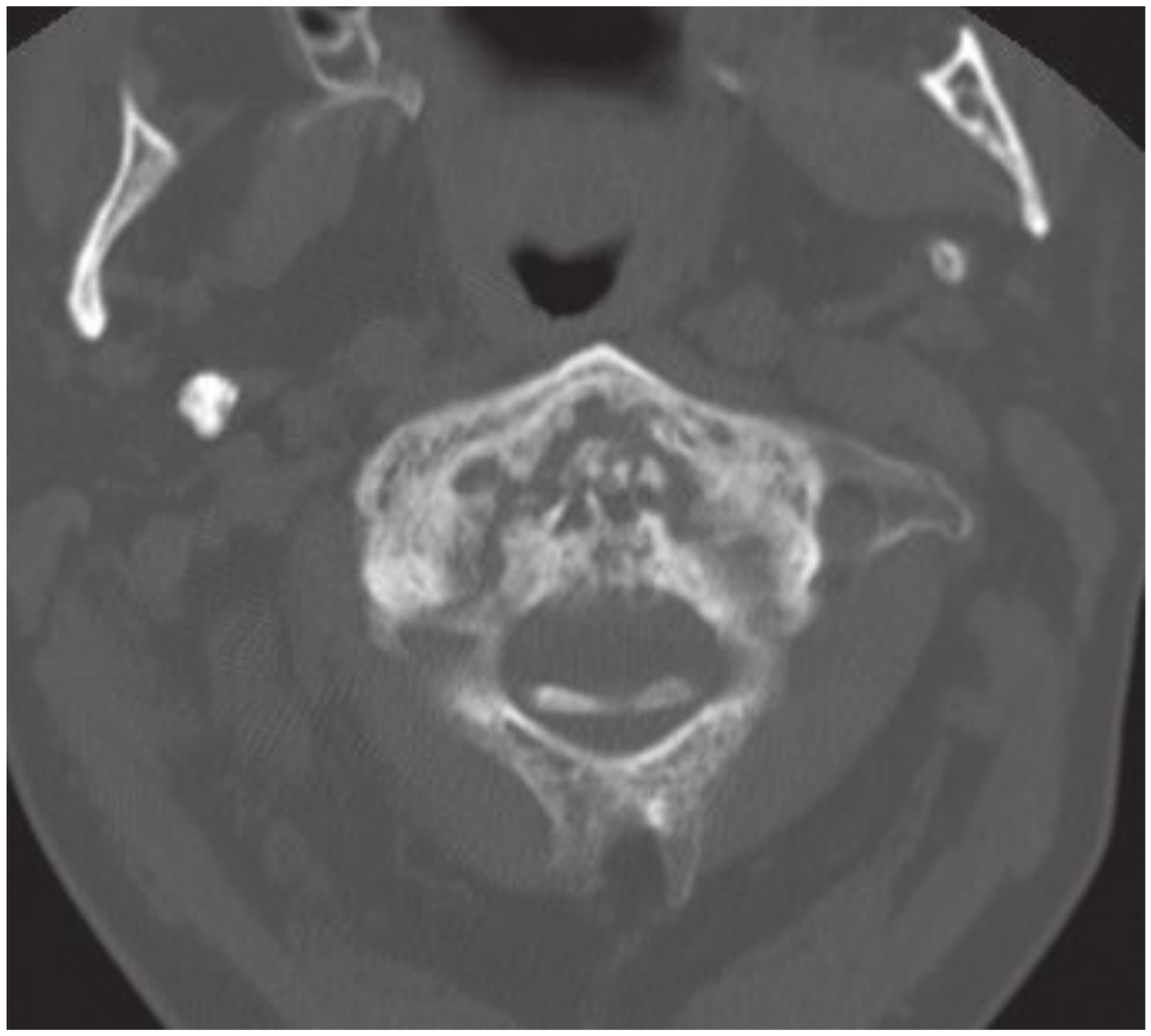


FIGURE 15-31 This CT shows severe changes of rheumatoid arthritis in the cervical spine at C1-C2. This patient would have significant atlanto-occipital instability.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

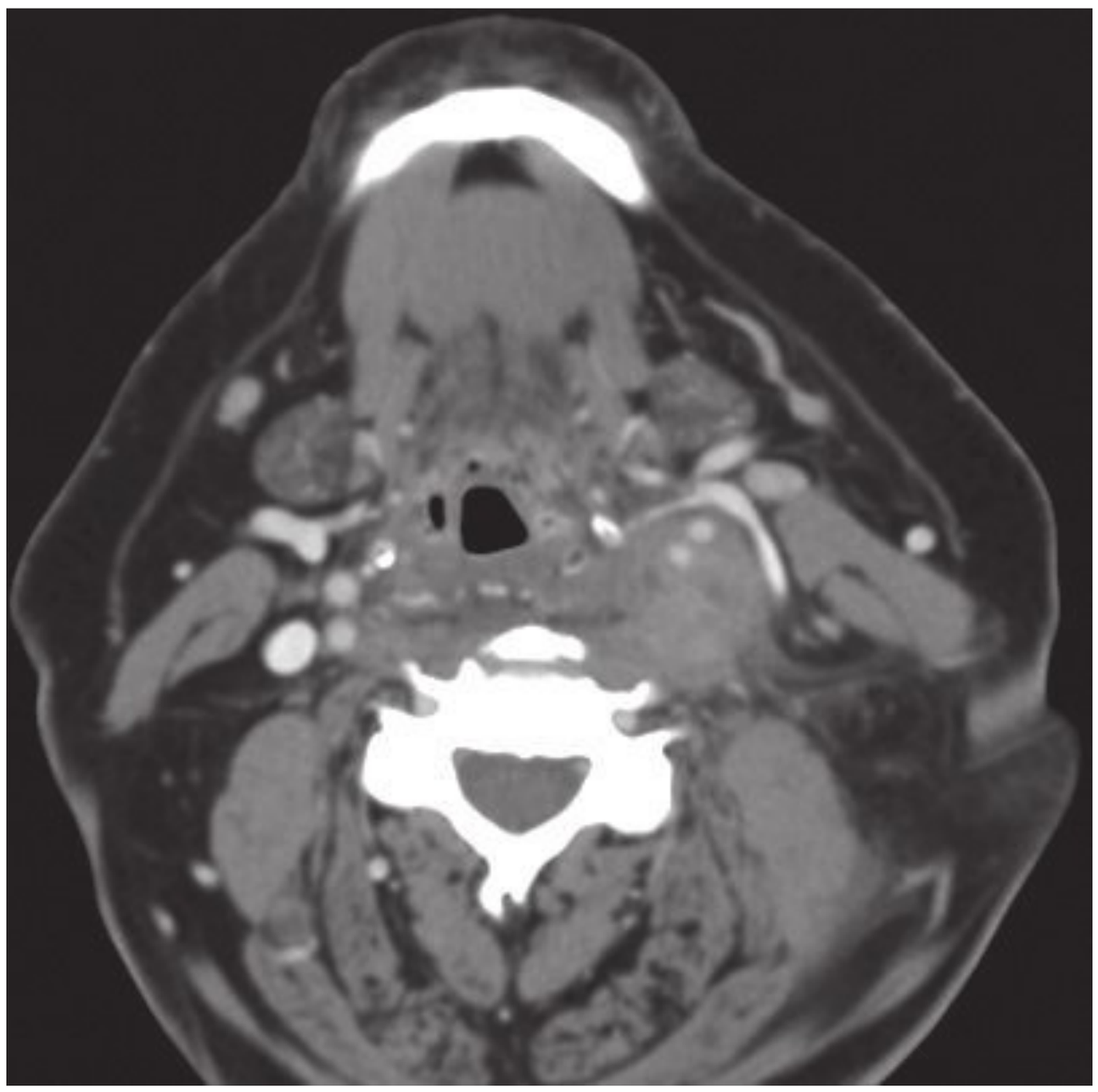


FIGURE 15-32 Hematoma of the carotid sheath from a pseudoaneurysm is evident in this CT scan, resulting in localized tissue distortion and compromise of the upper airway.

(Courtesy of Dr. Barton Branstetter, Department of Radiology, University of Pittsburgh Medical Center.)

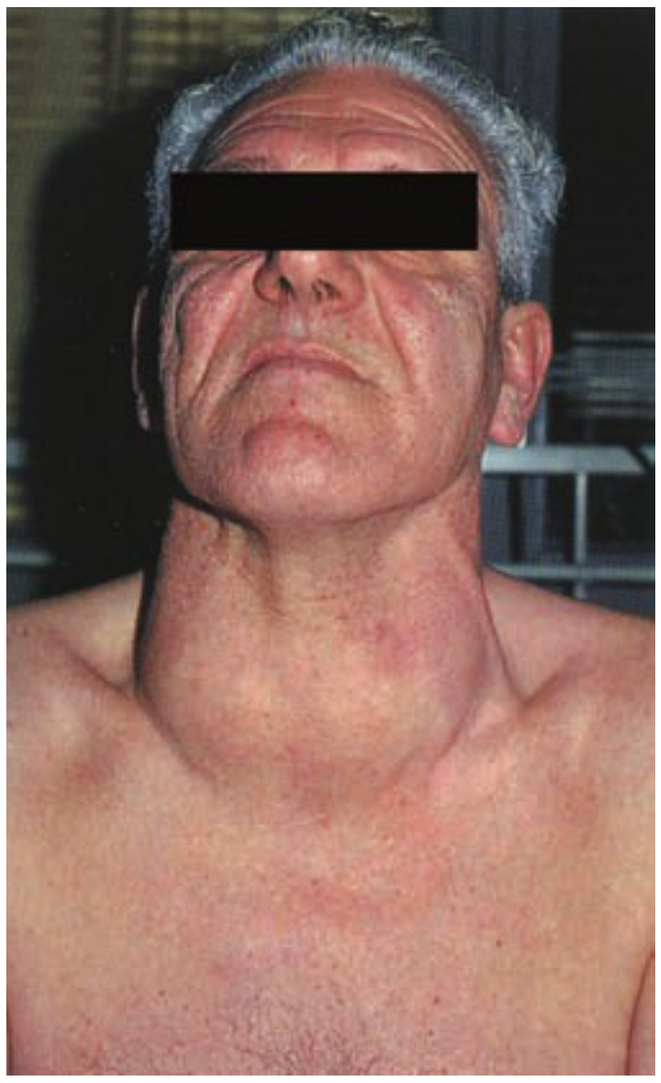


FIGURE 15-33 Markedly enlarged thyroid gland.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

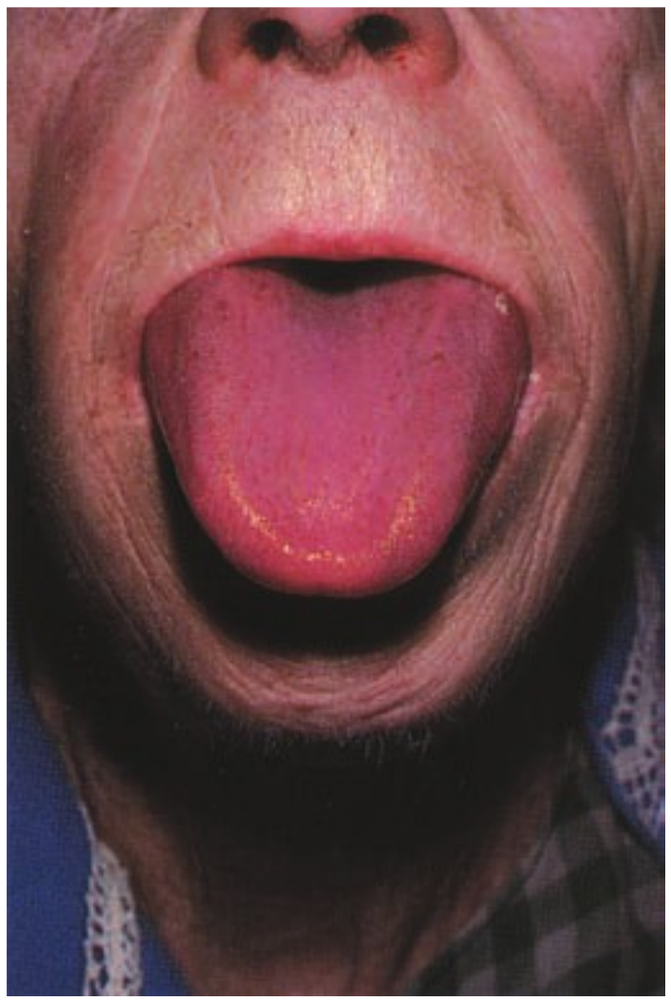


FIGURE 15-34 Enlargement of the tongue in amyloidosis.
(From Benjamin B, Bingham B, Hawke M, et al. A Color Atlas of Otorhinolaryngology. Philadelphia, PA: JB. Lippincott Co; 1995, with permission.)

PART III

Adjuncts to Direct Laryngoscopy

CHAPTER 16

Mirror Blades and Prism Blades

Matthew J.P. LoDico and Raymond M. Planinsic

Concept

When the glottis is difficult to visualize via traditional direct laryngoscopy (DL), indirect line-of-sight devices have been used to facilitate endotracheal tube (ETT) placement. Two physical objects that can change the angle of reflected light are the mirror and the prism. These have been incorporated into laryngoscopic blades with varying success. The mirror blades enable a more "anterior" view of the larynx by reflecting the light. However, this reflection comes with the price of an inverted image, which can make initial use awkward. Two examples of blades that incorporate mirrors are the Siker blade[1] (Fig. 16-1) and the Neustein blade. The Neustein involves a mirrored attachment to the MacIntosh (Mac) blade that includes a guide channel for a stylet, over which the ETT is passed following blade removal.[2]

The prism can also be harnessed to obtain a better laryngoscopic view, and its utility has been understood since the early 20th century. It was not until the 1960s when Huffman described a prism made from Plexiglas that the concept came to fruition and became practical for use in airway management. Huffman's prism was designed for attachment to the standard MacIntosh blade, and provided a generous 30° of light refraction (Figs. 16-2 and 16-3).[3] A subsequent evolution of the prism blade is the Belscope. This is a derivation of the straight blade, with a 45° angulation at its midpoint as well as a design that incorporates an optional prism, and is available in three sizes.[4] Although these devices may improve a grade 3 or grade 4 view of the larynx, they may also reduce the room needed for manipulation of the ETT in the mouth.

One of the limitations of using either prism or mirror blades is the potential for fogging. This challenge can be overcome by warming the devices before use, or the addition of a defogging solution. However, this preparatory work cannot be managed easily outside of the operating room (OR). In these settings, the Airtraq, another prism-based device, can be of great use. The Airtraq is essentially a self-contained single-use airway device with mirrors and a prism at its heart (Figs. 16-4 and 16-5). The device is constructed of plastic and is therefore more resistant to fogging. For routine OR use, inclusion of an antifog solution is advisable; however, the device is functional in an emergency without such accessories. It also has the advantage of being one integrated tool, and therefore it is impossible to misplace or scratch the integral prism, which is all too easy to do with the small Huffman devices. The Airtraq

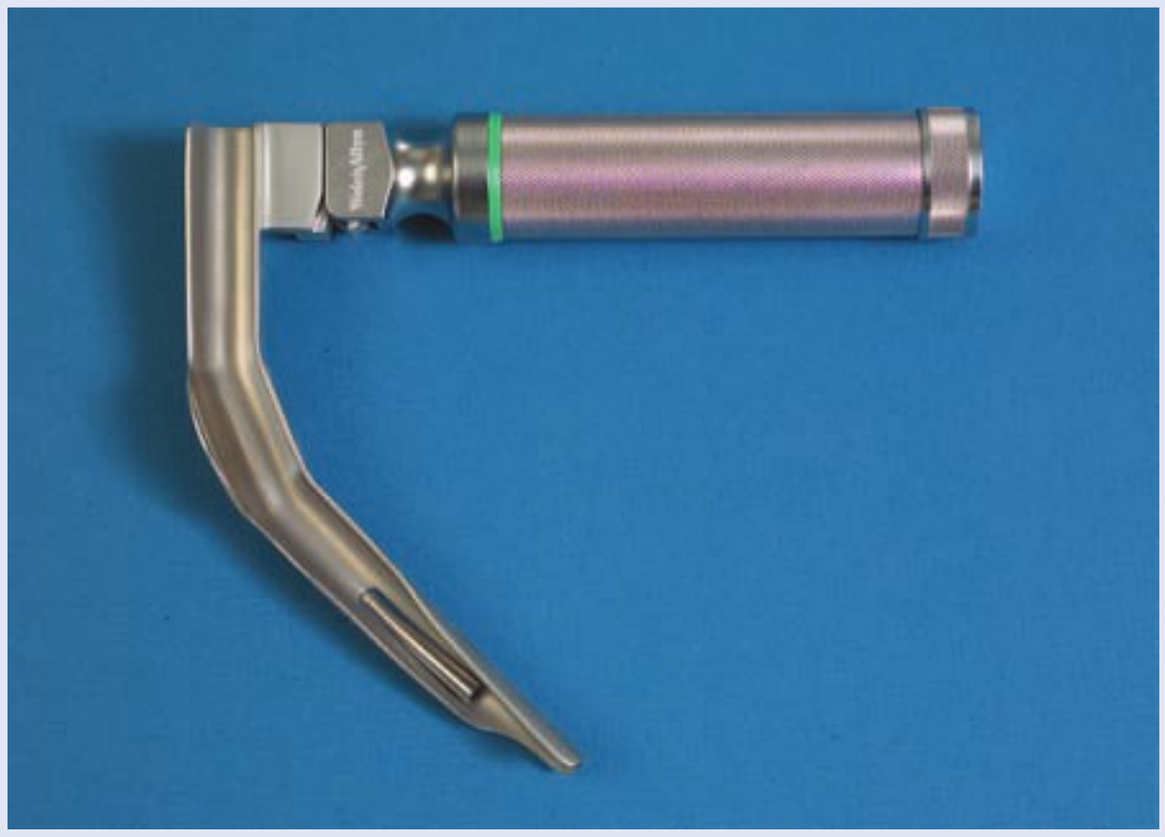


FIGURE 16-1 The Siker blade.



FIGURE 16-2 Prism for 3 Mac blade.



FIGURE 16-3 Prism for 3 Mac blade, mounted.



FIGURE 16-4 The Airtraq device.



FIGURE 16-5 Internal view of Airtraq device. Note prism and mirrors, as well as multiple lenses.

comes in several sizes, designed for oral, nasal, and double lumen endobronchial intubation. Indications for use include airway management in patients who are at risk for difficult intubation,[5] morbidly obese,[6] and/or in cervical spine immobilization.[7] The Airtraq would therefore be uniquely suited to be included among equipment on ambulances and in difficult airway bags. In these situations, in which space is quite limited, inclusion of more technically advanced and significantly more expensive adjuncts (such as a rigid optical stylet or fiberoptic bronchoscope) is seldom practical. The Airtraq also has an optional wireless display screen with a reusable camera that can be attached. This screen view increases both field of view and discrimination of objects and can be useful when training airway novices.

Evidence

The evidence for the use of mirror blades is anecdotal, rather than comparative. Siker, in his original description of the blade, described 99% success in intubating a series of 100 patients, including several cases in which standard blades had provided a poor view of the larynx.[1] No comparative trials of prisms are available. The efficacy of these devices has been established only anecdotally. In his original description of the device, Huffman[3] reported he was able to effectively visualize the glottic opening with the prism device in each of 35 patients, including those with large, protuberant teeth. The Belscope's effectiveness was evaluated by its originator, after whom it is named, and has been applied successfully in patients with normal anatomy as well as those with difficult airways.[8] Bellhouse reported his experience with more than 3,500 intubations using his blade and reported it "wholly successful." In 12 cases of failure of the Mac blade, and 7 cases of known or encountered difficulty with DL, the blade was effective.[4] Only rarely was the prism used.

The Airtraq has been evaluated in a number of mostly small, (n = 40 to 100) randomized studies comparing the effectiveness of the device head to head with DL or other adjuncts for a given indication.[5–7] One of these studies included patients with expected difficult airways and who were intubated with either a MacIntosh blade or the Airtraq device. The authors found that the Airtraq was both faster (mean time (SD); 13.4 (6.3) vs 47.7 (8.5) s), and had fewer failures. There were four failures in the MacIntosh group of 20, which were eventually intubated with the Airtraq.[5] In another comparison of intubation with the MacIntosh blade vs the Airtraq, in morbidly obese patients, a similarly significant shorter time to intubation with the Airtraq was evident, as well as the need to use it to rescue several failed intubations in the MacIntosh group. In addition, the Airtraq reduced the fraction of patients who developed reduced oxygen saturation ($SpO_2 < 92$) during intubation.[6] Finally, a different study that evaluated intubation in patients whose cervical spines were immobilized provided evidence of a significantly shorter time to intubation with the Airtraq, with the only failure of intubation occurring in the MacIntosh group.[7]

Preparation

- Standard preparations for DL
- If a prism (Huffman) or a mirror (Siker) is to be used, they should be placed for several minutes in warm water to avoid fogging, or a defogging solution should be applied.
- The Airtraq should be opened and defogger applied, or in case of emergency proceed to laryngoscopy. An ETT should be placed in the coaxial channel of the device.

Procedure

MIRROR (Figs. 16-6 and 16-7)
- attach Siker blade to laryngoscope handle
- perform DL
- note inverted image...etc

PRISM (Figs. 16-8 and 16-9)
- place prism on vertical flange of Mac blade (Fig. 16-3)
- repeat laryngoscopy, using view through prism to bring glottis into view (Fig. 16-9)
- in addition to the subheading issue above the airtraq section of "procedure" needs to be broken up as such:

AIRTRAQ (Figs. 16-10 and 16-11)
- insert the device in the midline, following the curve of the blade
- with eyepiece perpendicular to the ground, lift the device up away from the bed (Fig. 16-10)
- center the vocal cords in the viewfinder (Fig. 16-11)
- if the cords are not visible, tilt the eyepiece toward the feet, effectively withdrawing the device incrementally, and then return to perpendicular and repeat the lifting procedure
- when a view of the laryngeal inlet is evident and centered in the eyepiece, push the ETT out of its channel and through the vocal cords

Practicality

MIRRORS AND PRISMS
- inexpensive
- simple in concept
- portable, but they can easily be scratched and small prisms are frequently misplaced
- not familiar; requires practice in vivo and in vitro especially with the inverted images from the mirror blades

AIRTRAQ
- relatively inexpensive for a "video " type blade
- portable and self-contained
- disposable single use (may be an advantage or a disadvantage)
- does not require warming or defogging procedure

Indications

- Poor laryngoscopic view (grade 3 or 4 view).

Contraindications

- Usual contraindications to DL
- Lack of familiarity with devices

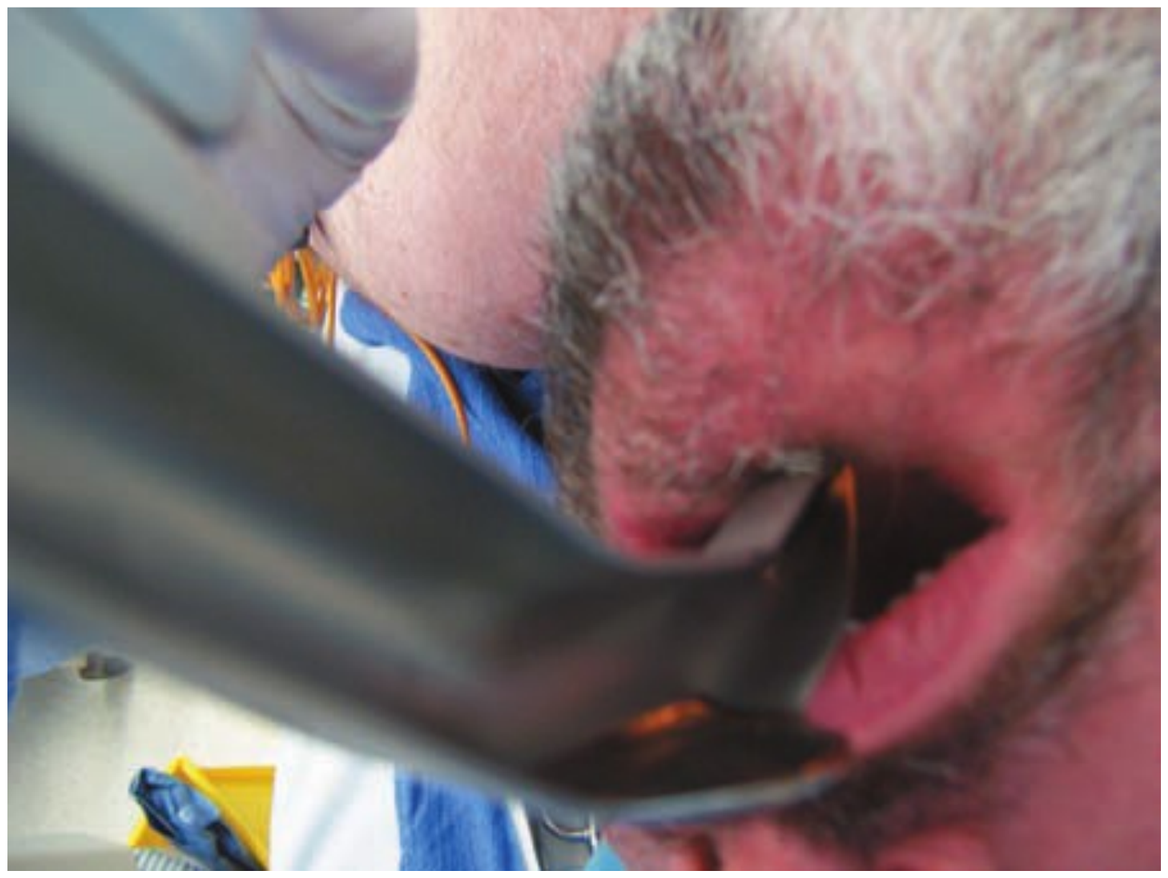
Complications

- Similar to those of DL
- Inability to place ETT using inverted image (with the mirror blades)
- Fogging of mirror or prism obscuring image

Acknowledgments

Airtraq photos by David Pinkerton

FIGURE 16-6 Insertion of the Siker blade into the mouth. Note the relatively high vertical profile of the blade.



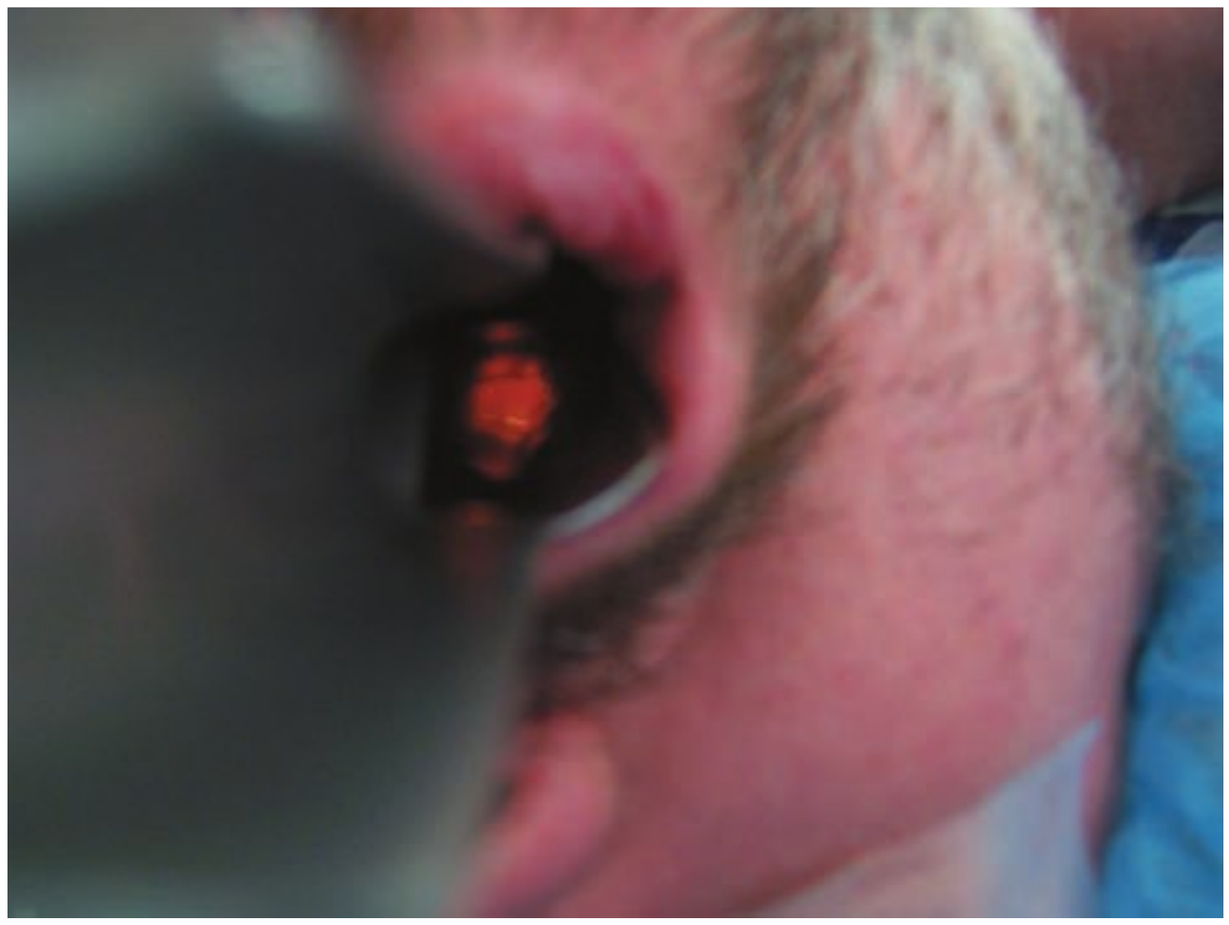


FIGURE 16-7 Grade 2 view of the glottis as reflected in the mirror of the Siker blade.

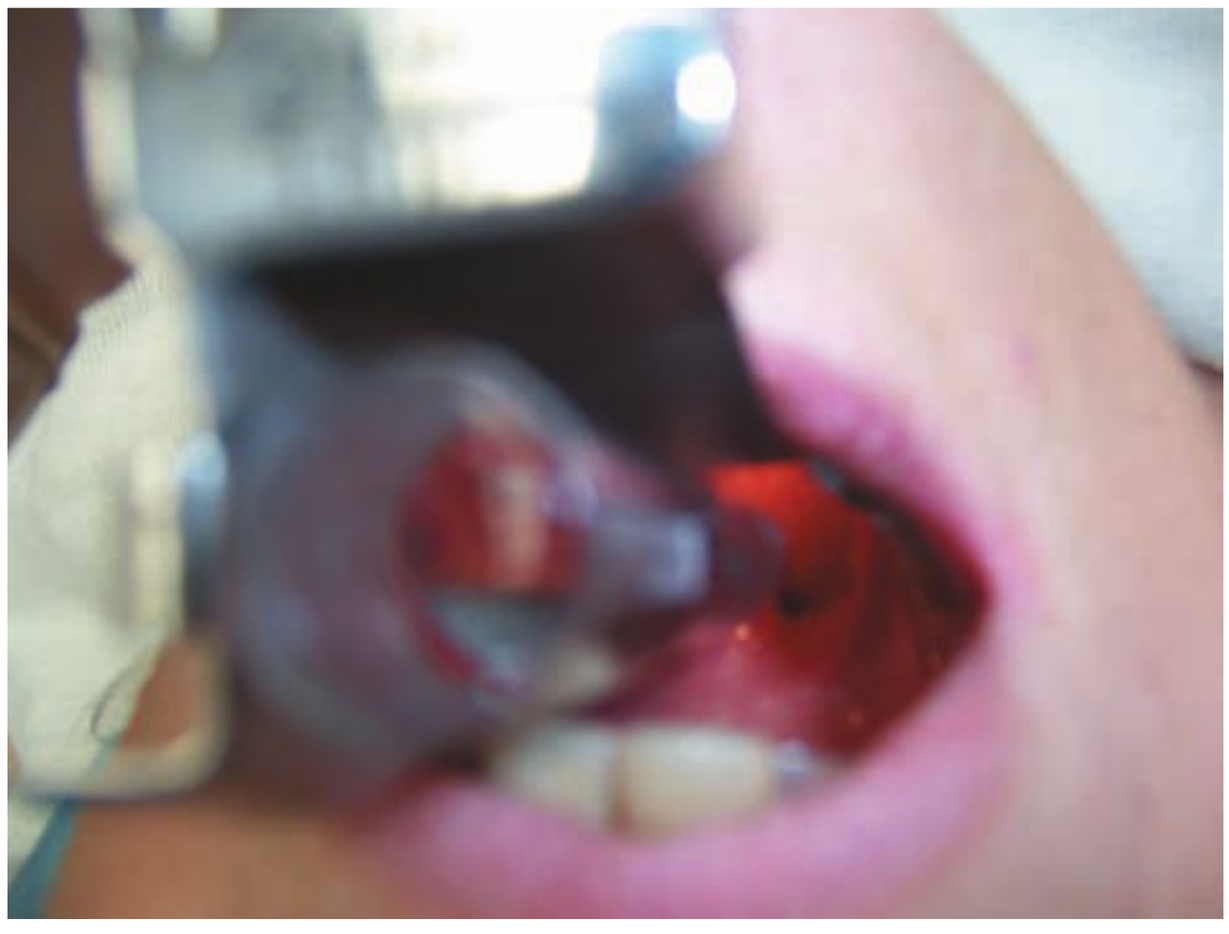


FIGURE 16-8 A poor view of the larynx using DL with 3 Mac not viewed through the prism.

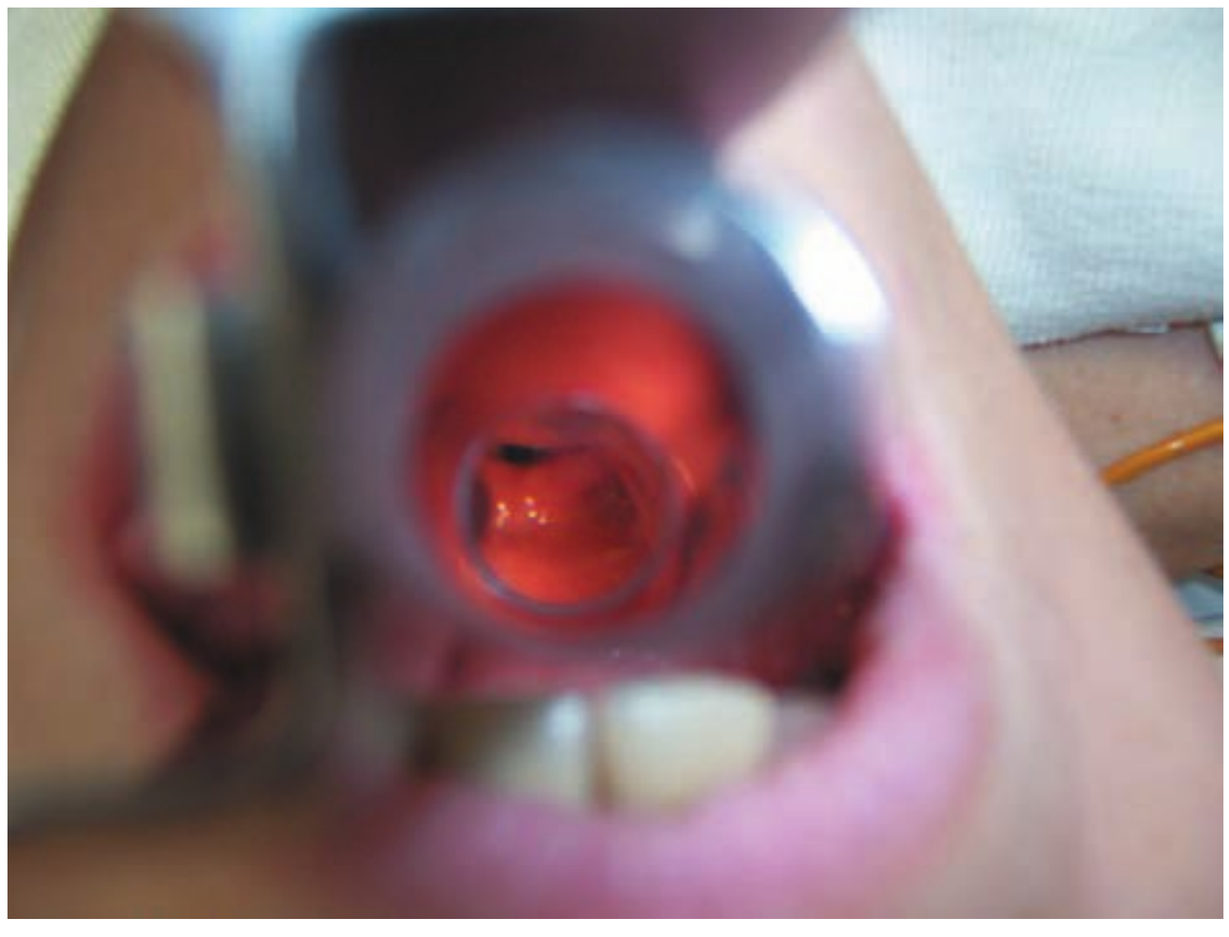


FIGURE 16-9 Laryngoscopy with prism on 3 Mac blade, showing view through prism: the airway is evident as grade 2 view.

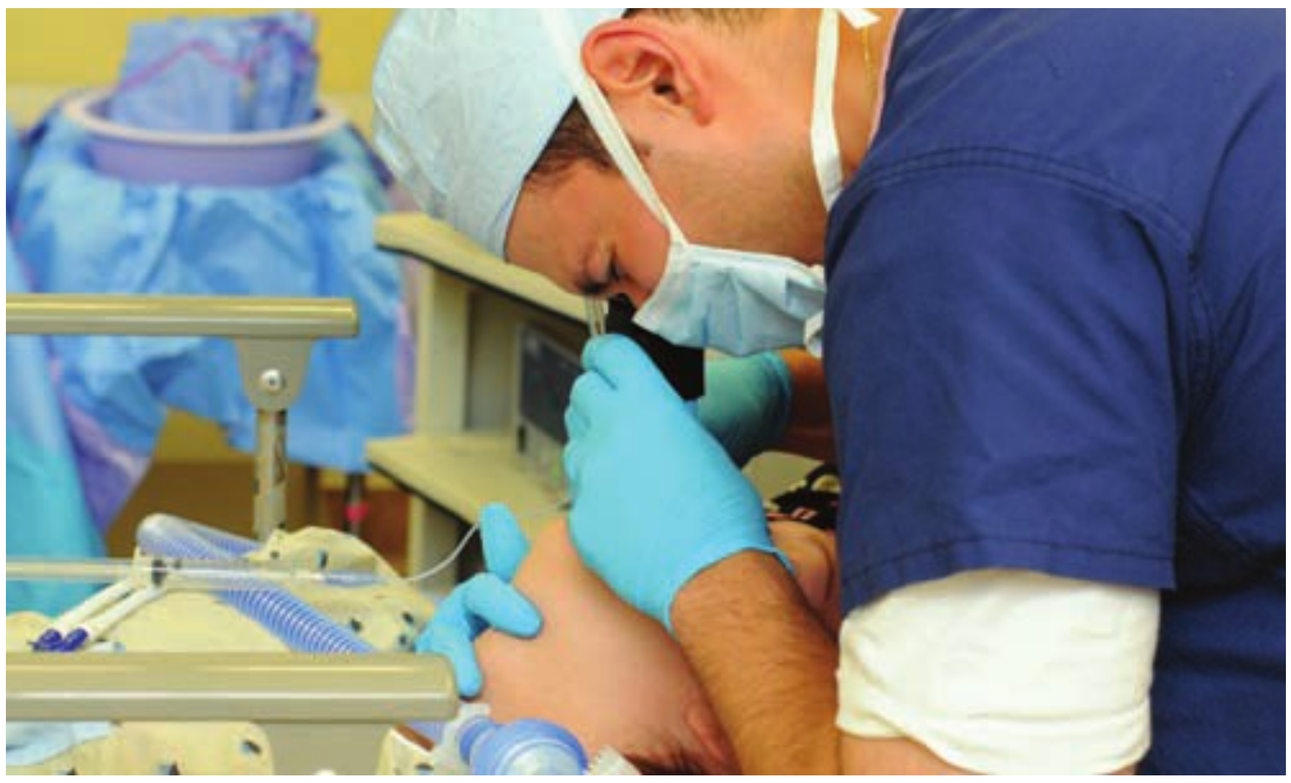


FIGURE 16-10 Performing laryngoscopy with the Airtraq. Note the need for the operator to place his eye in contact with the device.

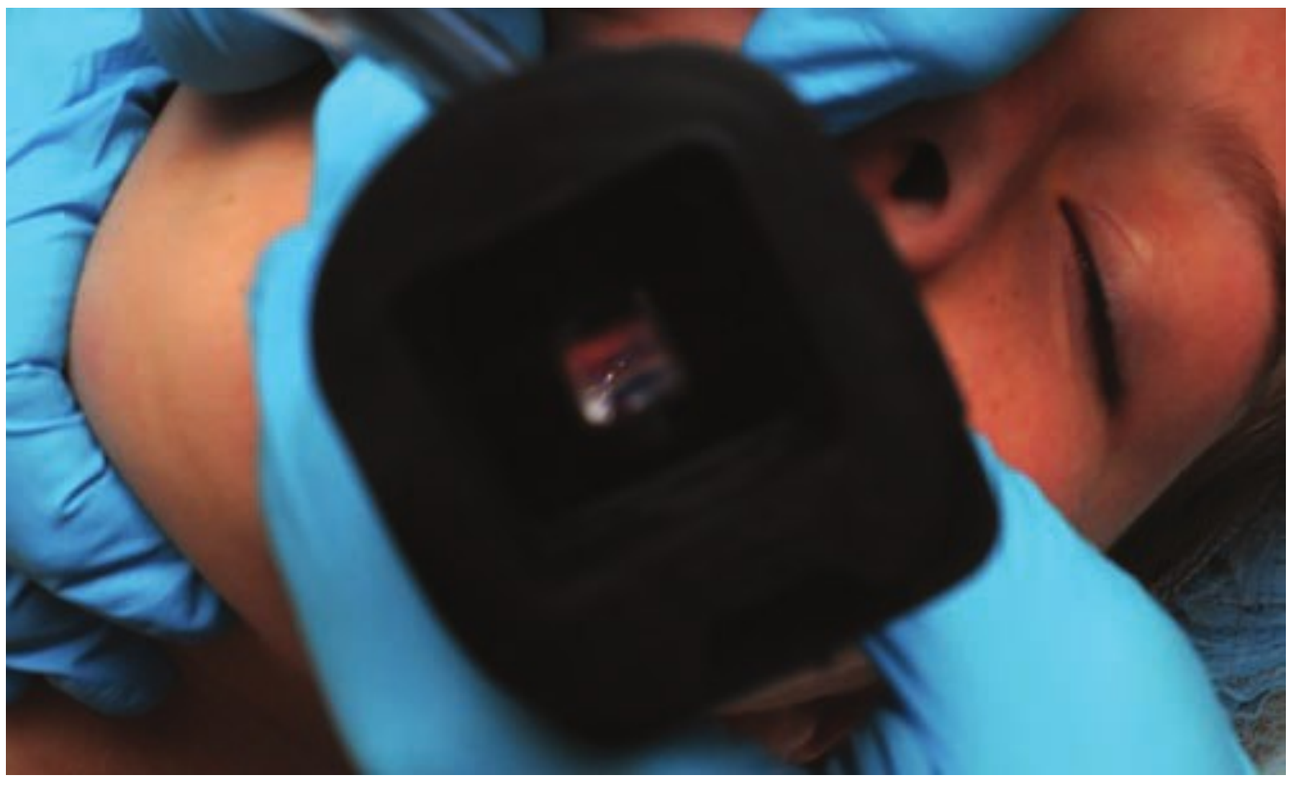


FIGURE 16-11 Grade 1 view of the glottis through the viewfinder of the Airtraq.

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CHAPTER 17

Bougies and Airway Stylets

Pranav Shah and Erin Sullivan

Concept

During unanticipated difficult intubations, emergencies, or when direct laryngoscopy provides a poor view (Cormack-Lehane Grade III) or reveals a very tight glottic opening, it is often beneficial to insert a guiding catheter ("gum elastic bougie" or GEB) prior to attempting endotracheal tube (ETT) placement.

The GEB provides several advantages. It has improved maneuverability compared with an ETT. The GEB's combination of firmness and an angulated tip provides a means to intubate the glottic opening when it is poorly visualized, if its location can be inferred from the view of the interarytenoid notch or the position of the epiglottis. Additionally, the GEB can provide a tactile clue that it has been placed correctly in the airway, as its stiff end often moves against the cartilagenous tracheal rings. Of note, the GEB can provide a second form of tactile feedback because continuing to insert the bougie will lead to resistance if placed in the trachea. This resistance occurs when the angled tip of the bougie is too wide to fit through the narrowing bronchi. It usually occurs at an insertion depth of 30–35 cm. Generally, no resistance is felt if placed in the esophagus.

The malleable Eschmann introducer with its stiff, angulated distal tip lends itself to this task because it is small enough to be maneuvered in the pharynx where it is used to "probe" for the glottic opening. Its end is firm enough to rattle against the tracheal rings as it is placed in the airway, providing a sense of correct placement. This type of introducer is 60 cm long, 5 mm in diameter, with distal 2.5 cm angulated at approximately 40°. It has markings for every 10 cm.

The Frova intubating introducer similarly facilitates intubation when the glottic view is poor. This device is a hollow cannula with a malleable, removable steel stylet, which permits "jet" (high pressure) ventilation through an adaptor, or oxygen insufflation during intubation attempts. It is 65 cm long, 4.7 mm in diameter, with distal 2.0 cm angulated at 65°. The introducer comes with a rigid stylet that is 10 cm shorter than the introducer thereby decreasing the risk of trauma on insertion.

Airway exchange catheters can also be used as ETT introducers. However, these devices lack a curved tip to provide tactile feedback regarding which lumen is being cannulated.

Evidence

Numerous case reports and case series attest to the value of the bougie in difficult intubations in the operating room (OR), emergency department, and in the prehospital setting. A significant proportion of these studies were carried out in the United Kingdom.

There have been several papers that have elucidated optimum technique for GEB use. Dogra et al identified several steps that increased success using GEB. These included keeping the laryngoscope blade in the mouth during ETT placement and rotating the tube 90° counterclockwise if the ETT became lodged at the glottic opening.[1] Additionally, Latto et al collected data on 200 cases of GEB use by anesthesiologists in the United Kingdom between October 1997 and August 1998. Of 200 uses, 146 were for "poor view of the larynx" and 46 for "difficulty pushing the tube toward the larynx." Their survey revealed that 178 cases were intubated on first try with GEB and 15 on the second attempt. Six required more than two attempts, and one attempt at inserting GEB failed. Moreover, "clicks" of the tracheal ring were present in 65% of cases (130) and only 13% had distal resistance. They recommended that the distal end of the GEB be further bent to a more acute angle prior to use, as well as inserting the GEB to 45-cm depth before declaring that the device had encountered no resistance and hence was likely in the esophagus. Furthermore, their survey revealed that in 45% of the cases laryngeal pressure improved the view of the glottic opening, and in 51% there was no change, whereas it worsened the view in only 2% of cases. Hence, they also recommend optimum positioning of the patient along with attempted laryngeal pressure as part of their routine technique to obtain the best glottic view.[2]

Several case reports show GEB use increases success in difficult airway scenarios. Combes et al trained 40 anesthesiologists on a manikin over 2 months on a difficult airway algorithm where GEB was the first line tool in a "can ventilate, cannot intubate" scenario. In the prospective portion of the study over next 18 months, 89 scenarios occurred, and, in 80 cases, GEB allowed the ETT to be successfully placed.[3] Komatsu et al examined the role of GEB in anesthetized patients with simulated restricted neck immobility using a cervical collar. There was a 90% intubation success rate using GEB. Of note, the authors

also reported a 100% success rate with a video laryngoscope.[4] Nolan and Wilson studied intubation in 157 patients with manual cervical stabilization applied, and found that with GEB, all 78 patients in the GEB group were intubated in less than 45 seconds, and that GEB was used successfully in the 5 intubation failures in the direct laryngoscopy group[5]. Furthermore, Maruyama and colleagues studied the difficulty of intubation using video laryngoscope, GEB, and standard direct laryngoscopy in manikins undergoing chest compressions with or without manual cervical stabilization. These authors found that intubation via video laryngoscope was more readily accomplished than that with GEB, which in turn was easier than standard direct laryngoscopy.[6]

Moreover, several authors have examined GEB use outside the OR. Jabre et al evaluated GEB use in the prehospital setting where intubation was necessary. After training on a manikin, intubation reports were collected for the next 30 months. Of the 1,442 intubations, 41 attempts required GEB placement. It was successfully placed 33 times (78%).[7] Shah et al[8] reported use of GEB during intubation for various reasons in 88 cases over 17 months in a large academic emergency medicine department and reported a success rate of 80%. Also, some authors have found GEB useful in modifying other airway techniques. GEB also has been used to assist in cricothyrotomy in an animal laboratory setting[9] and in placing a Proseal laryngeal mask airway (in this technique, GEB was purposefully placed in the esophagus to guide the LMA to an optimal position).[10]

The success of the Eschmann stylet has led to the development of several different varieties of bougies. Braude et al[11] compared several types in a simulated difficult airway and found that the Portex single use GEB was inferior to Sunmed, Greenfield, and Eschmann GEB. Janakiram et al[12] compared the Pro-Breath GEB (the new version of Portex GEB), the Frova introducer, and the traditional Eschmann GEB on manikins, and found the Eschmann and Frova devices to be superior. Hodzovic et al[13] also examined various types of GEB and stylets in manikins and found that the peak force applied at the distal tip was greater with Frova catheters than with Eschmann GEB.



Preparation For Direct Laryngoscopy With Bougie Or Airway Stylet (Fig. 17-1)

- Anesthetized, preoxygenated patient, prepared for DL (chapter 5)
- Lubricate bougie lightly
- Enlist aid of an assistant



Procedure (Figs. 17-2 to 17-5)

- Proceed with direct laryngoscopy and establish best possible view (Fig. 17-2)
- Attempt laryngeal pressure to see if it improves the glottic view
- Identify interarytenoid notch at the back of the glottis, if possible
- Place distal (angulated) tip of bougie above the notch, or below the epiglottis
- Probe for the opening of the glottis
- Gently insert bougie, feeling for tip against tracheal rings (Fig. 17-3)
- If tip does not encounter rings, continue insertion. (If using Frova introducer, remove stylet before continuing insertion) (Figs. 17-1 and 17-2)
- At approximately 28 cm to 30 cm from teeth, the bougie will encounter resistance as it enters one of the bronchi and its tip encounters the smaller airways. *If this does not occur by 35 cm, the bougie is usually in the esophagus*
- Pull bougie back from resistance
- Have assistant place ETT over the proximal end of bougie
- Leave laryngoscope in place and elevate soft tissues during advancement of the ETT
- The assistant then holds proximal end of bougie, preventing its advance, as the ETT is moved along it toward the glottis (Fig. 17-5)
- If ETT insertion meets resistance, rotate ETT 90° either to the right or left as the leading edge of the ETT is likely to get stuck at the glottic opening
- Guide ETT into glottis, maintaining position of bougie
- Insert ETT to desired depth
- Pull bougie back, remove from ETT
- Inflate ETT cuff, confirm placement

Practicality

- Simple concept, requires little practice
- Relatively familiar
- Portable
- Readily affordable

Indications

- Poor laryngoscopy grade (Cormack-Lehane III)
- Small glottic aperture
- Suspected cervical spine injury, in a patient requiring intubation

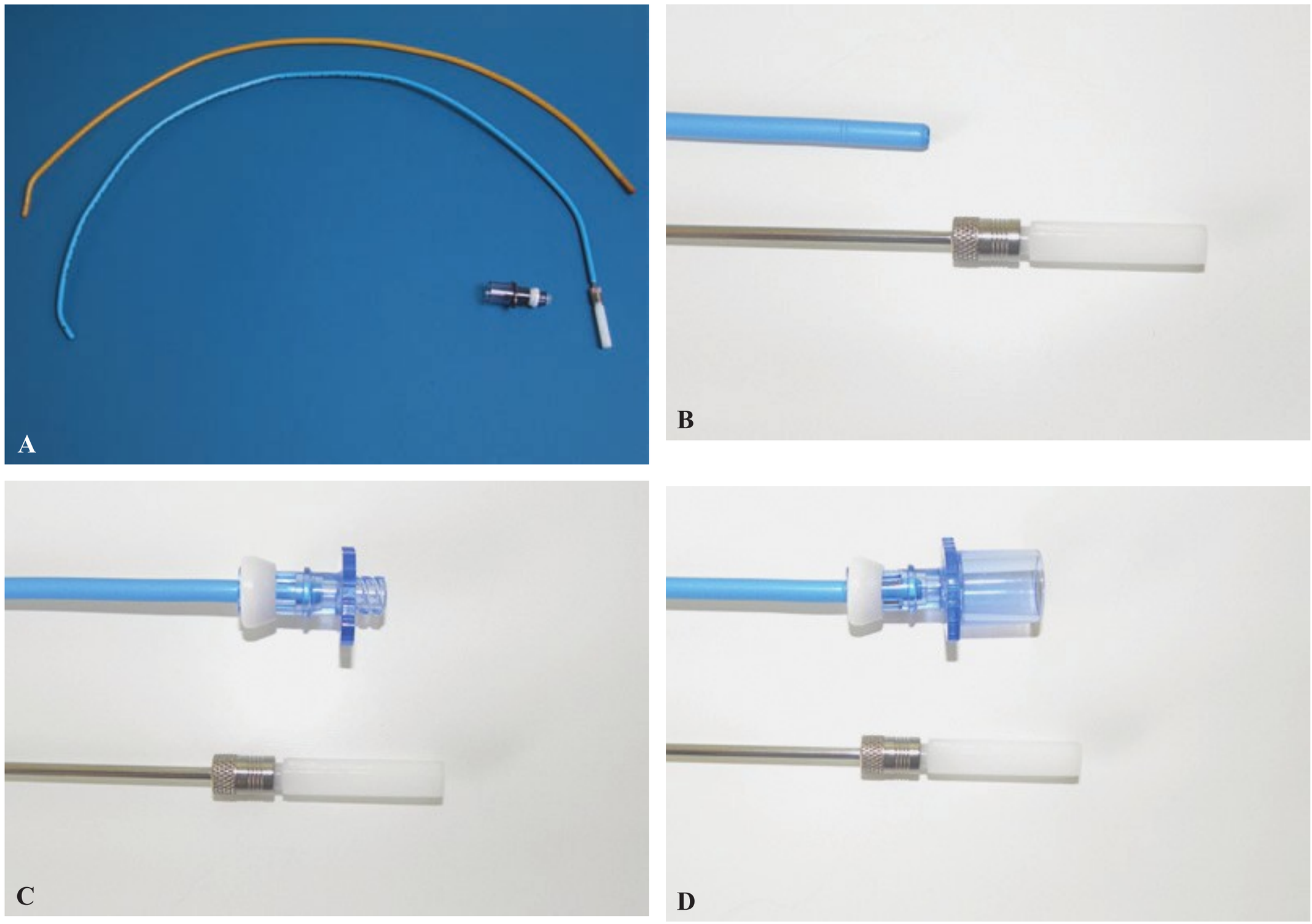


FIGURE 17-1 **A:** Eschmann stylet **(top)** and Frova intubating stylet **(bottom)**. **B:** Frova intubating introducer with stylet removed. **C:** Frova intubating introducer with stylet removed and adaptor for high-pressure oxygen insufflation attached. **D:** Frova intubating introducer with stylet removed and 15 mm adaptor for attachment to anesthesia circuit or resuscitation bag.

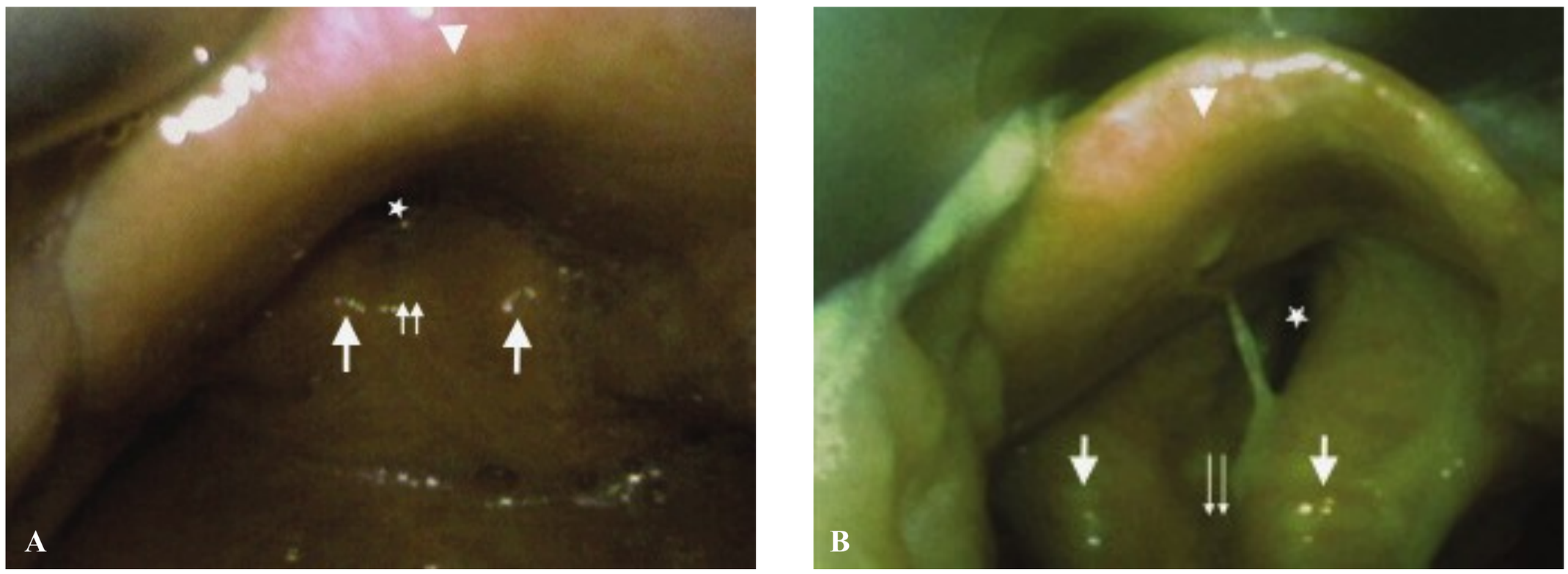


FIGURE 17-2 Laryngoscopic view prior to **(A and B)** and after the insertion of **(C)** Frova intubating. *Arrowhead* (Epiglottis). *Star* (Glottic opening). *Arrow* (Posterior Cartilages). *Double Arrows* (Interarytenoid notch). Frova intubating introducer was used in images **B** and **C** because the patient was known to have vocal cord paralysis of the right side leading to a small glottic opening as noted on laryngoscopy during previous surgery. Patient underwent successful cordotomy.

FIGURE 17-2 (Continued)

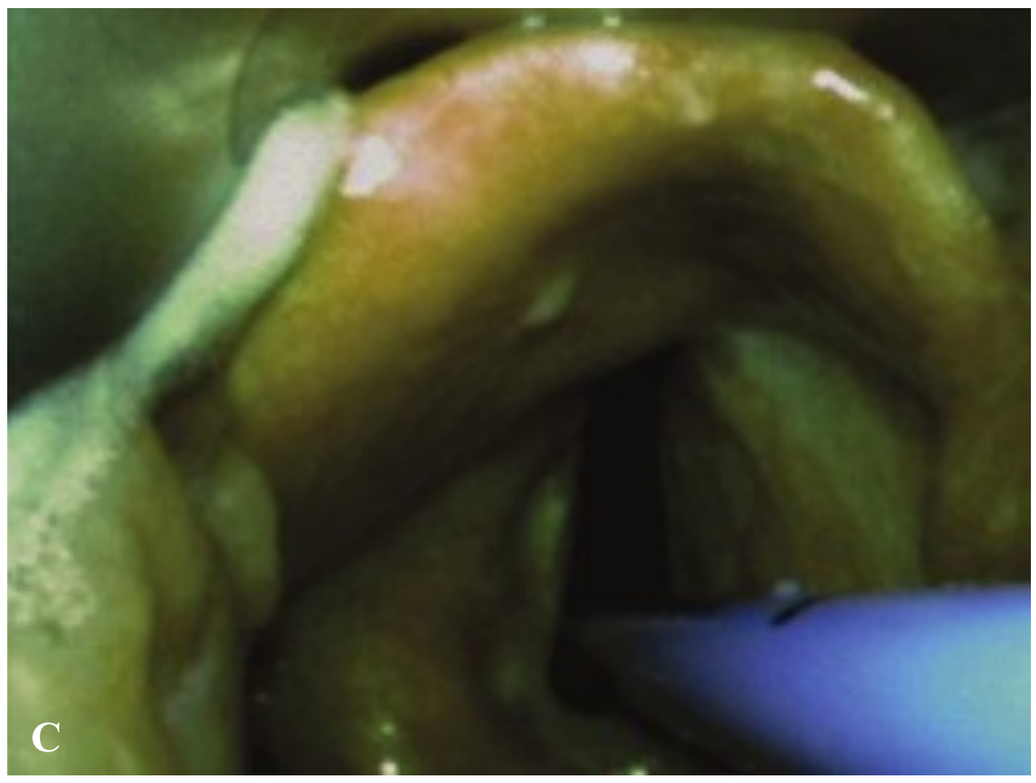
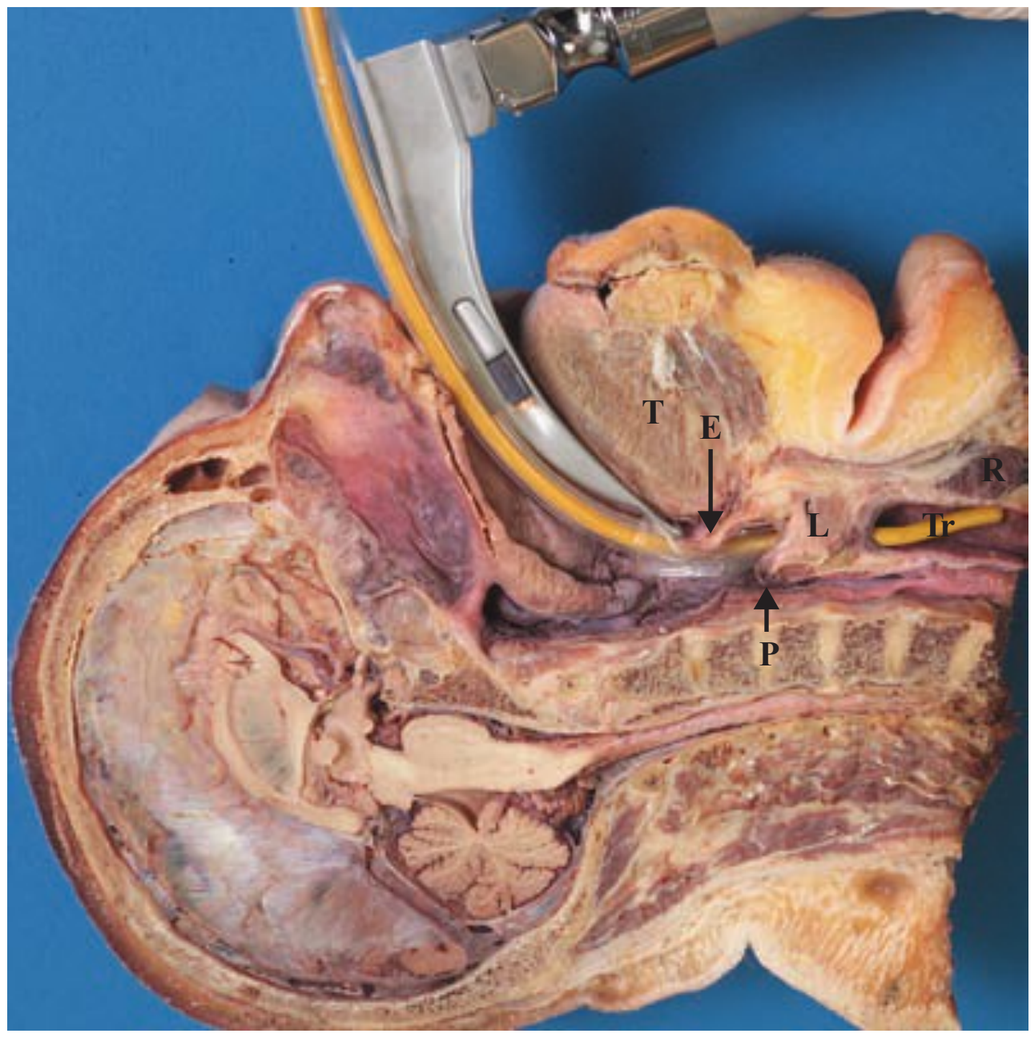


FIGURE 17-3 Midsagittal view of a cadaver during direct laryngoscopy with insertion of bougie into trachea and an ETT being inserted over the GEB. Note that in practice the end of the GEB will often be advanced more distally in the trachea before an ETT is inserted over the GEB to decrease the chance of the GEB being dislodged from the tracheal lumen. Often, ETT will meet resistance if the tip catches the posterior cartilages. If the tip of the ETT meets resistance (*arrows*) rotate ETT 90° and advance gently over the posterior cartilages. T, tongue; E, epiglottis; P, posterior cartilage; L, larynx; Tr, trachea; R, Tracheal ring.



Contraindications

- Similar to those of direct laryngoscopy
- Laryngeal disruption
- Inaccessibility of oral cavity

Complications

- Misplacement of ETT into esophagus can occur
- Tracheal rings may not be felt, even when placed correctly
- Trauma to larynx or bronchus may occur
- ETT can be advanced too far, into mainstem bronchus

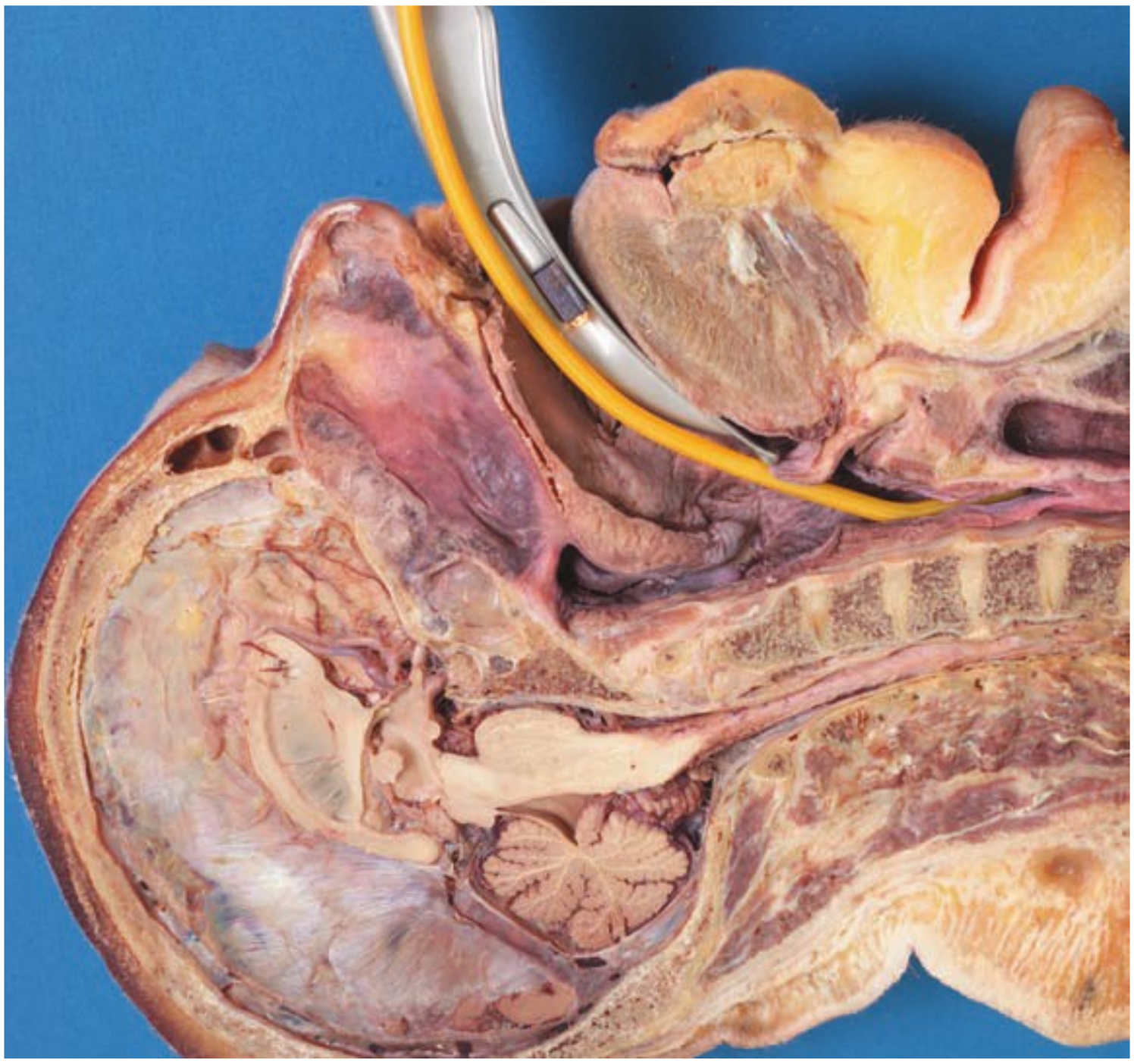


FIGURE 17-4 Midsagittal view of a cadaver showing bougie placed into esophagus (no resistance would be met in this situation as the bougie is advanced). If bougie is inserted into the esophagus, it can be advanced > 35 cm without meeting resistance.



FIGURE 17-5 **A and B:** Placing ETT over bougie with the help of an assistant. Note that the laryngoscope is maintained in the mouth to ease the passage of ETT, and the proximal end of bougie is fixed by the assistant to prevent migration of bougie.

FIGURE 17-5 (Continued)



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PART IV

Blind Intubation

CHAPTER 18

Blind Nasotracheal Intubation

Steve Orebaugh

Concept

Blind nasotracheal intubation (BNTI) remains a viable technique in the elective surgical patient and in emergency intubation, particularly for patients with challenging anatomy. In this procedure, an endotracheal tube (ETT) is placed through one of the nares into the nasopharynx (Fig. 18-1), then into the glottis, guided primarily by breath sounds, without visualization. At its best, it is a smooth, effective, and painless procedure. At its worst, BNTI is traumatic and uncomfortable and may make subsequent attempts at airway management more difficult by causing epistaxis or vomiting. BNTI requires preservation of spontaneous ventilation, so that audible inspiratory efforts can be detected and synchronized with tube placement. It is much less likely to be successful in the apneic patient. The breath sounds, when optimized, help to guide the tube into a position just above the glottis, so that controlled advancement of the tube allows correct placement. Whistles are available to attach to the end of the ETT to make ventilation through the ETT more audible, confirming placement of the tube in the airway. BNTI is less likely to be used in children than in adults, due to the lack of cooperation, the small size of the nares, and frequent hypertrophy of the adenoidal tonsils.

Evidence

BNTI is supported anecdotally by case reports and case studies in both the emergency medicine and anesthesiology literature. In the National Emergency Airway Registry, this method was used in about 5% of all intubations, with a success rate of nearly 86%.[1] In Dronen's[2] comparison of BNTI with direct laryngoscopy for intubations in the emergency department (ED), the 68% rate of successful endotracheal intubation was significantly lower than that for direct laryngoscopy, in which there were no failures. In addition, complication rates, mostly nasal bleeding and emesis, were much higher with BNTI. When paramedics used BNTI in 219 intubations, the rate of appropriate ETT placement improved from 58% to 72% when a directional tip control tube was used.[3] BNTI in children is typically reserved for cases in which other methods of intubation are not feasible.[4]

Preparation (Figs. 18-2 and 18-3)

- Soften the ETT in a warmed saline solution, if time allows (directional ETTs tend to be very soft and do not require this step)
- Check the patency of each nostril, through inquiry and physical examination (occluding each side and asking the patient to breathe through the nose can be revealing)
- Prepare the nose with local anesthetic gel or solution, and a vasoconstrictor (phenylephrine solution or oxymetazoline nasal spray)
- Placement of successively larger nasopharyngeal airways, coated with local anesthetic and vasoconstrictor, reduces epistaxis in the elective situation
- Sedation or anesthesia may be provided, but spontaneous respiration should be preserved
- Patient may be supine, or in seated position
- Standard preparations should be made for direct laryngoscopy (see Chapter 5)

Procedure (Figs. 18-4–18-8)

- Place ETT in nares (the right nostril is usually chosen, to allow the bevel of the ETT to approach the turbinates atraumatically)
- The tube is directed along the floor of the nasal cavity, parallel to the hard palate
- Place an ear near the proximal end of the ETT, listening carefully for breath sounds
- When the nasopharynx is reached, breath sounds become audible
- Gentle advancement of the tube should allow an increase in the sounds, as the glottis is approached



FIGURE 18-1 Sagittal section through cadaver specimen, showing floor of nasal cavity, turbinates, and nasopharynx: the path traveled by a nasotracheal tube.



FIGURE 18-2 Preparation for BNTI: nasal airways, local anesthetic gel, and topical vasoconstrictor solutions.

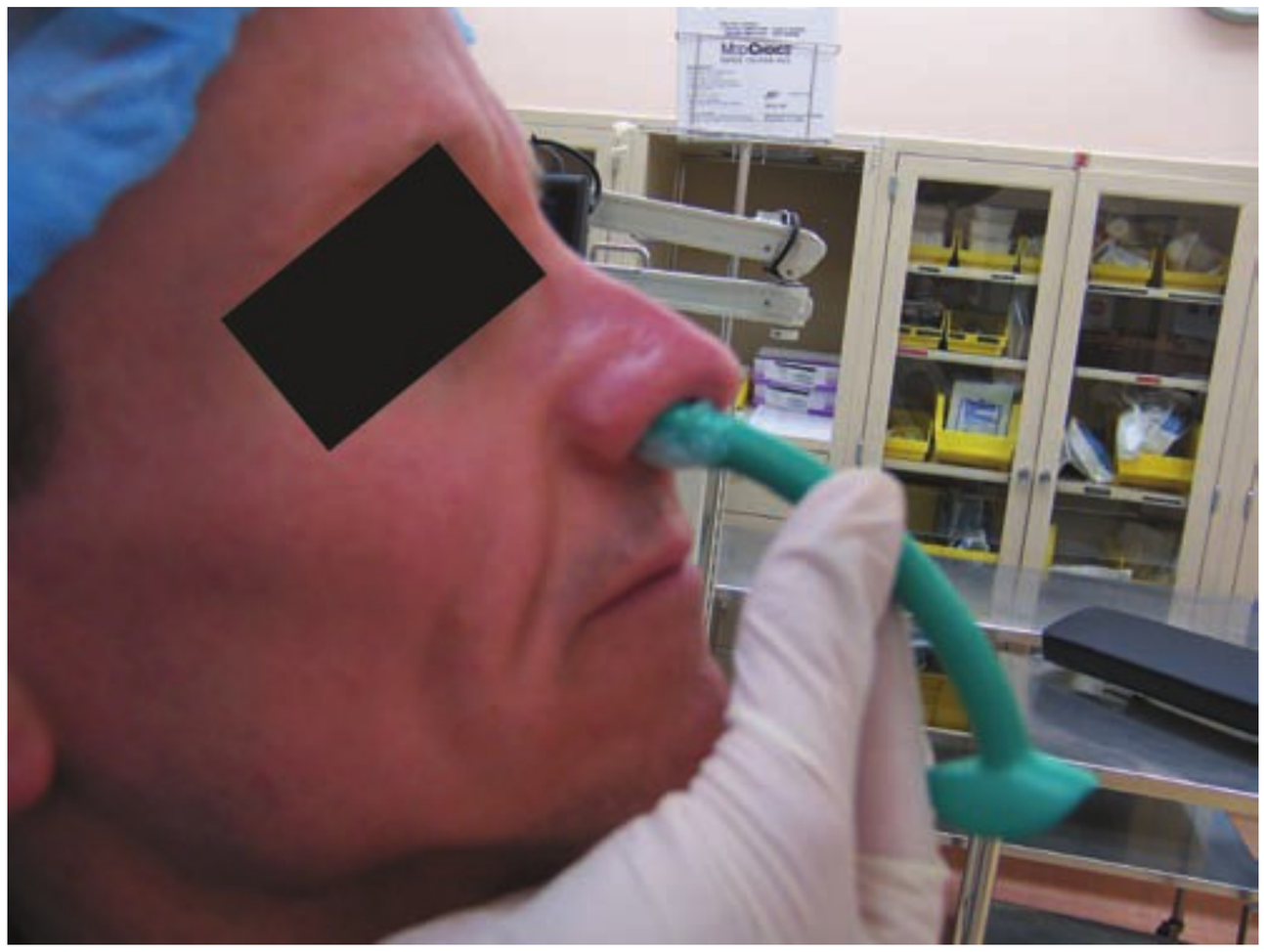


FIGURE 18-3 Dilation of the nose with nasal airways/lubricants/vasoconstricors.



FIGURE 18-4 ETT insertion, along floor of nose.



FIGURE 18-5 ETT in position in the hypopharynx: breath sounds should be maximally audible.

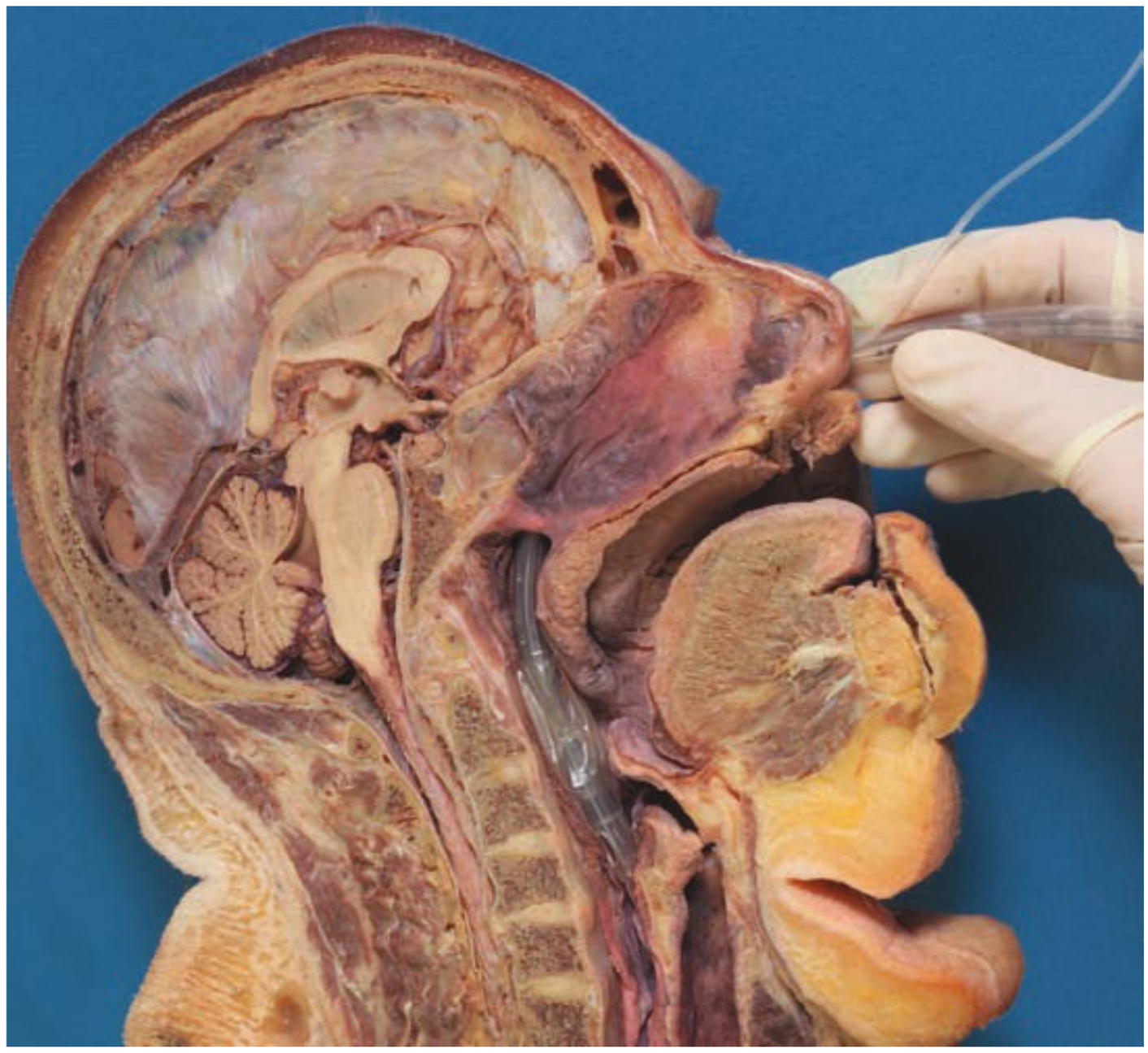


FIGURE 18-6 Tube misdirection (too far posterior). Neck extension will help to align the tube with the glottis.

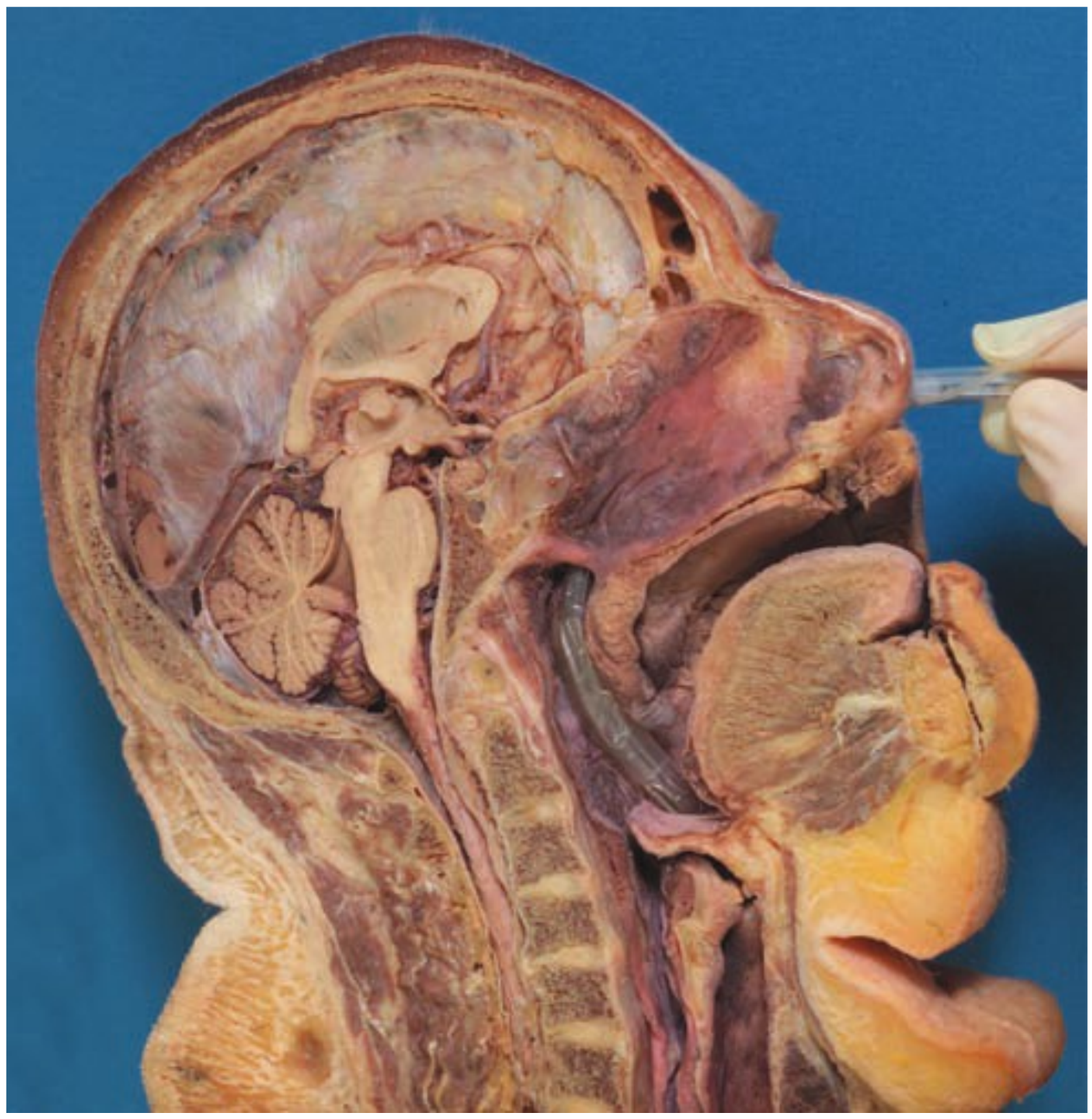


FIGURE 18-7 Tube misdirection (too far anterior). In this setting, the tube may be palpable above the thyroid cartilage. Neck flexion will help to align the tube with the glottis.

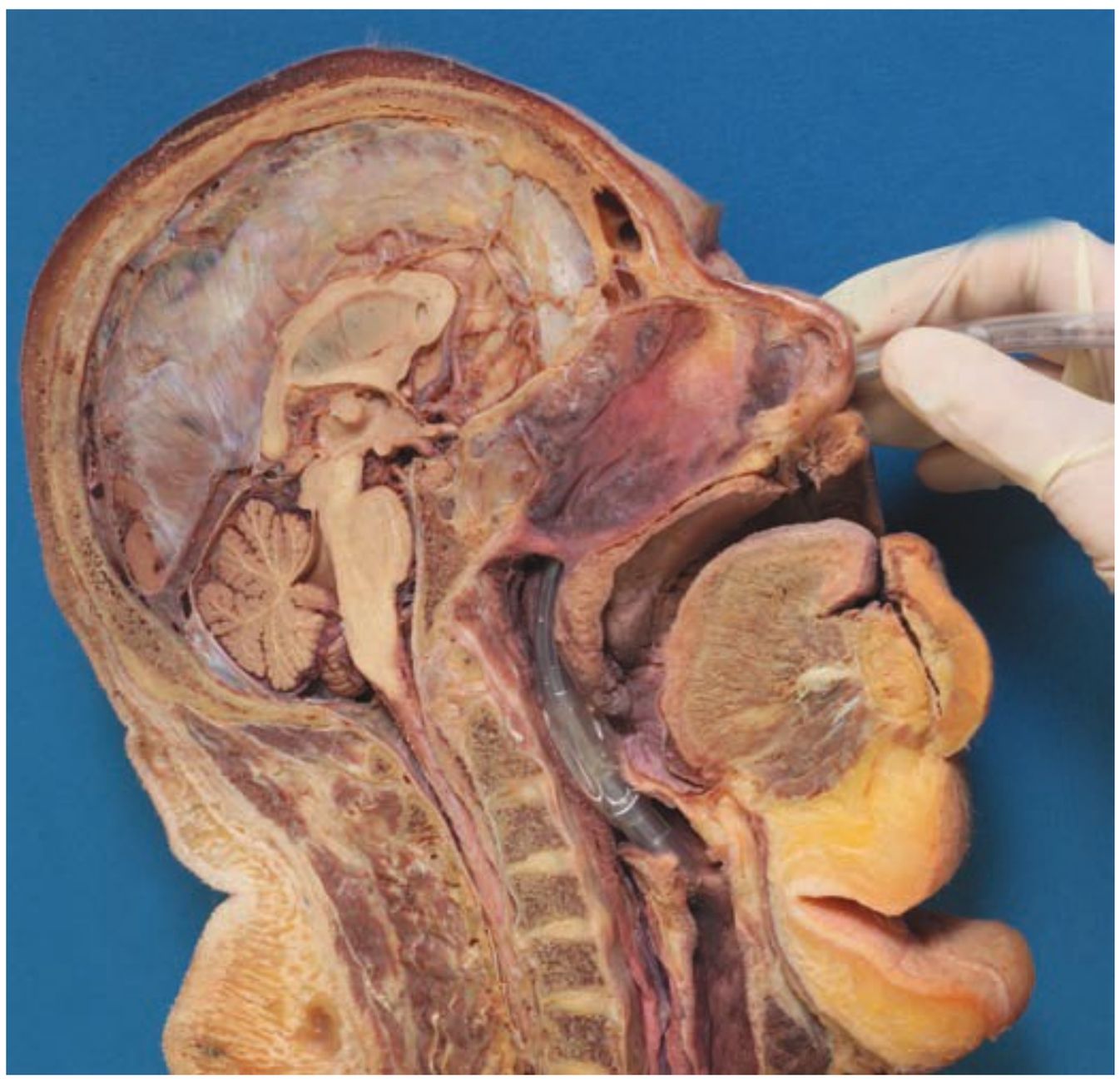


FIGURE 18-8 Correct position, advancing ETT into glottis.

- If breath sounds diminish, suspect the tube is advancing into the esophagus; withdraw and redirect or change head and neck position
- When the breath sounds are maximal, the ETT is held in place
- During the pause, breath sounds are carefully tracked
- The tube should then be advanced as inspiration is initiated
- If successful, patients breathe through the tube and cannot phonate
- When unsuccessful, changes in head position may assist in correct tube placement: extension brings the tube forward, whereas flexion of the neck brings its tip posteriorly
- Directional tubes, if used, allow the tube tip to be redirected
- If the tube moves into the piriform recesses, lateral to the glottis, on advance (sometimes palpable in the neck), rotation of the tube can help to direct its tip medially, toward the laryngeal orifice
- Tube placement is confirmed in the usual fashion

Practicality

- The technique is simple, portable, and easily affordable
- BNTI may not be familiar, as it is not as popular as it once was, so it may require practice to understand how to direct head and neck position changes to facilitate intubation, as well as to learn to take cues from breath sounds

Indications

- Anatomy that suggests difficult direct laryngoscopy
- Need for intubation while preserving spontaneous ventilation
- Inaccessibility of the oral cavity

Contraindications

- Coagulopathy
- Atresia of nares
- Other causes of nasal cavity obstruction
- Enlarged adenoids
- Apneic patient (relative—procedure is less successful)
- Upper airway trauma or obstruction
- Facial or nasal trauma distorting nasal anatomy
- Major head trauma
- Suspected cervical spine injury

Complications

- Turbinate injury or avulsion
- Nasal hemorrhage (may be severe)
- Gagging, choking, emesis
- Aspiration of gastric contents
- Misplaced ETT
- Pharyngeal trauma
- Laryngeal trauma
- Placement of tube intracranially

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CHAPTER 19

Blind Orotracheal Intubation

Steve Orebaugh

Concept

When tools for laryngoscopy are unavailable or unreliable, endotracheal tube (ETT) insertion may be facilitated by using the fingers to guide the tube through the glottic opening,[1,2] or by the use of a device designed to guide the tube through the oropharynx and into the glottis. Examples of the latter include the Williams airway intubator and the Berman intubating airway.[3,4] In digital intubation, the index and long fingers of the nondominant hand are placed in the hypopharynx, feeling for the epiglottis anteriorly. They are then used to elevate and guide the tip of the styletted ETT just under the epiglottis, into the larynx. If reaching the epiglottis (at least) or glottis (optimally) is not possible due to short fingers or a deep larynx, the technique will be much less reliable and essentially becomes a blind thrust toward the glottis. With the Williams or Berman guides, the device is inserted into the mouth of the anesthetized or unconscious patient and the tube inserted blindly through it to be guided toward the glottis.

Evidence

Little systematic testing of these techniques has been performed, nor are there useful comparative trials. Digital intubation is most likely to be used when highly unfavorable conditions for direct laryngoscopy exist, such as unavailability of a laryngoscope, copious amounts of blood or fluid in the airway, or the failure of all other techniques. It is more readily applicable in children than in adults, due to the short distance between the mouth and glottis. Case reports attest to its utility in difficult pediatric airway management.[5,6] The Williams airway has been used to provide blind orotracheal intubation in the operating room in more than 300 cases, with a success rate of 80%.[4]

A. DIGITAL INTUBATION

Preparation

- Same as for direct laryngoscopy (see Chapter 5)
- Double gloving adds a measure of protection
- Lubricate the stylet, place in the ETT
- Bend the ETT into a "field hockey stick" shape
- The patient must be anesthetized and relaxed (to avoid trauma to the operator and to stimulate reflexes with coughing or emesis) or unconscious
- Either sniffing position or neutral head position are acceptable
- Preoxygenate, if time allows

Procedure (Figs. 19-1–19-4)

- Stand beside the patient, facing the top of his/her head, with the nondominant hand closest to the head
- The index and long fingers of the nondominant hand are placed into the oropharynx
- The epiglottis is palpated and lifted with the fingers
- If the epiglottis cannot be palpated, an assistant pulling on the tongue may elevate it to the point at which it can be palpated
- The ETT is introduced and guided between the two fingers
- The dominant hand advances the tube along the groove between the index and long fingers, curving around the base of the tongue
- While the index and long fingers guide the tube, it is advanced up under the epiglottis and into the glottis
- The stylet is removed, ETT cuff inflated, and tube placement is confirmed

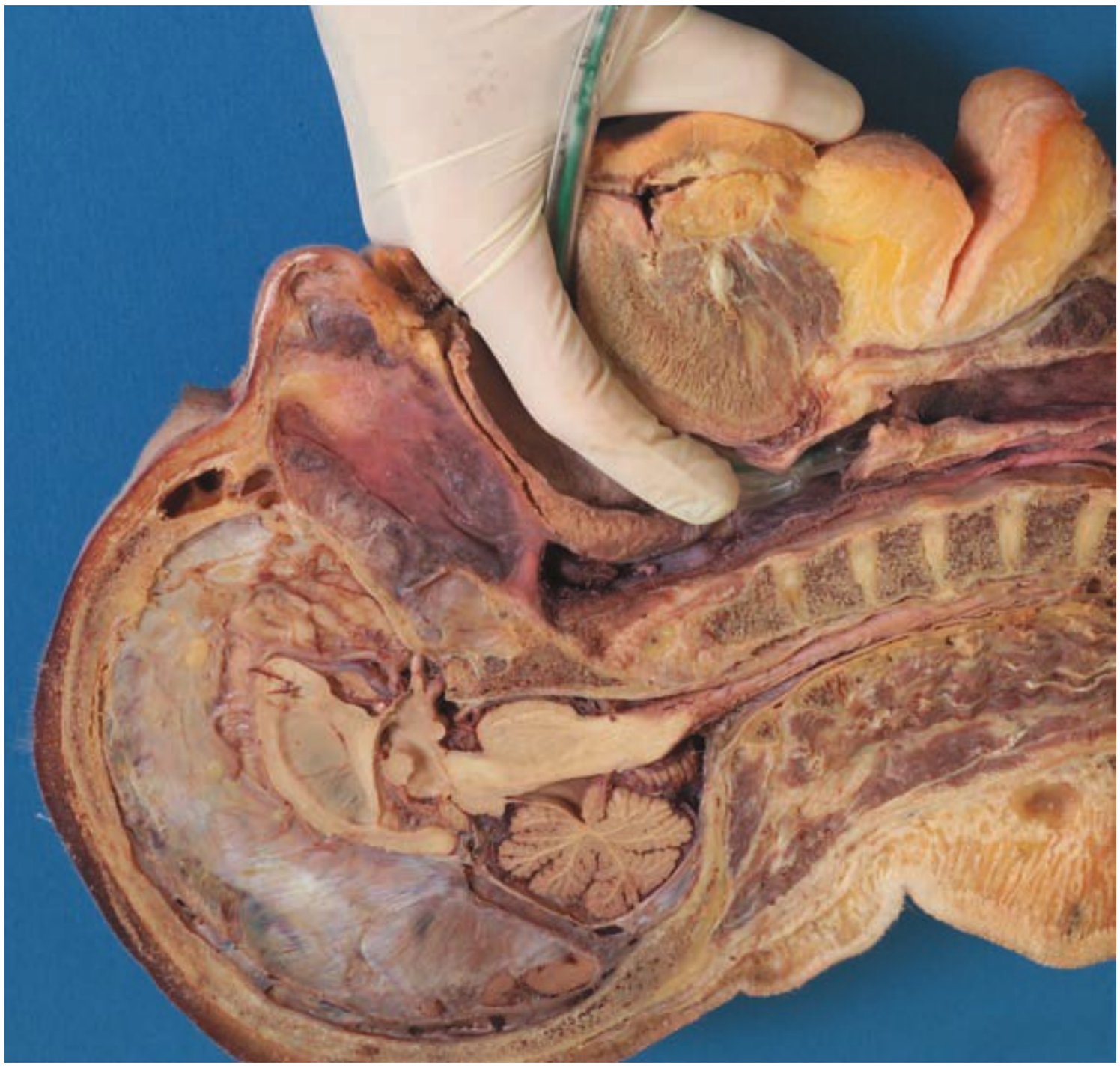


FIGURE 19-1 Digital intubation demonstrated in a cadaver specimen.



FIGURE 19-2 Fingers of nondominant hand, thrust behind tongue, lifting epiglottis.



FIGURE 19-3 ETT insertion, guided toward glottis by index and long fingers.



FIGURE 19-4 ETT advancing through glottis, guided by fingers.



FIGURE 19-5 Berman and Williams airways, to facilitate blind orotracheal intubation.



FIGURE 19-6 Placement of Williams airway in oropharynx in cadaver specimen.

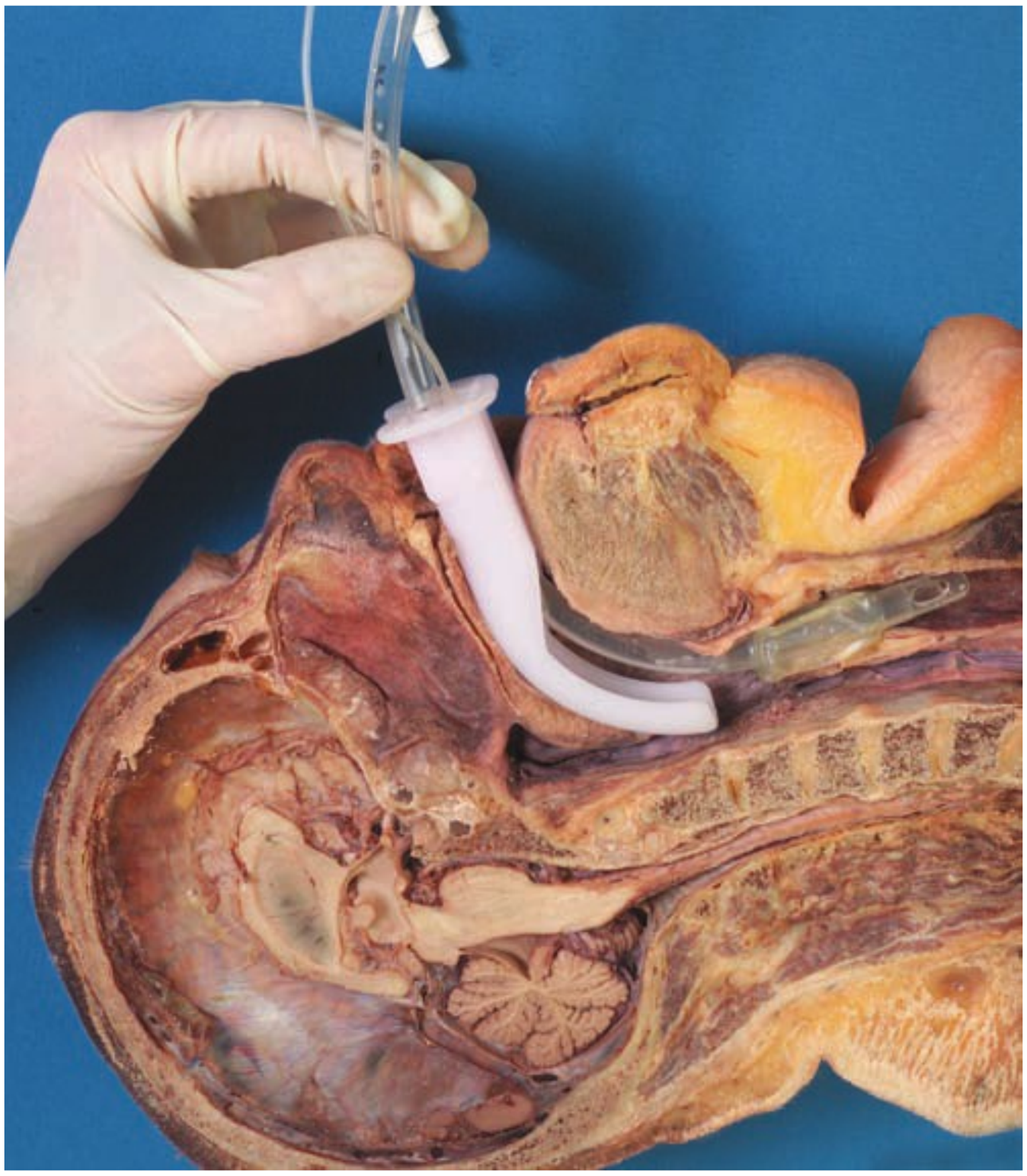


FIGURE 19-7 Advancing ETT through Williams airway blindly into glottis.

- Alternatively, the index and long fingers of the nondominant hand can be inserted into the mouth with the curved, styletted tube held between them
- As the fingers locate the glottis, the other (dominant) hand is used to advance the tube into the airway
- The stylet is removed, ETT cuff inflated, and tube placement confirmed

B. BLIND INTUBATION THROUGH A WILLIAMS AIRWAY INTUBATOR

Preparation

- Same as for direct laryngoscopy (see Chapter 5)
- Lubricate the ETT
- The patient should be anesthetized or unconscious, preoxygenated, and in neutral position

Procedure (Figs. 19-5–19-7)

- Williams airway intubator is inserted, its distal extent curving around the back of the tongue
- Lubricated ETT is inserted through the intubator
- Tube is gently advanced into the glottis
- If resistance is met, the ETT is withdrawn and the airway intubator position modified, after which further attempts are conducted
- Once placed, ETT cuff is inflated, and its position is confirmed in the usual fashion

Practicality

- Simple, portable
- Little or no cost
- Unfamiliar to most—practice is desirable in patients or cadavers

Indications

- Lack of laryngoscopy equipment
- Failure of other techniques
- Copious secretions or blood in the airway
- Patient in position that precludes direct laryngoscopy

Contraindications

- Inability to palpate epiglottis (digital technique)
- Inability to open the mouth
- Infectious process or foreign body of airway
- Disrupted larynx, or severe oropharyngeal trauma (unless no alternative means of managing the airway exists)
- Conscious patient, or patient with intact airway reflexes

Complications

- Misplacement of ETT
- Trauma to pharynx or larynx from blind ETT insertion
- Injury to the hand of the person intubating (digital technique)

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PART V

Lightwands and Optical Stylets

CHAPTER 20

Lightwands

Anthony Silipo and Ryan Romeo

Concept

The lightwand places a light source at the tip of the endotracheal tube (ETT). After the lightwand is threaded through the tube, the two are advanced blindly into the pharynx, aiming for the glottis. A "halo" of light visible over the front of the neck provides guidance for insertion of the tube and lightwand into the glottis, using gentle probing or rocking maneuvers. Transillumination of the larynx confirms that the tube is indeed being advanced into the airway.

In the late 1950s, Yamamura[1] described transillumination for use in nasotracheal intubation. The use of the lighted stylet, or lightwand, has been well described since then, as a blind technique in the setting of difficult laryngoscopy, as well as for routine airway management.[2–4] Early commercial lightwands suffered from poor illumination and misdirection of the light, so that a darkened room was necessary to see the halo produced in the glottic area during insertion into the airway. The lamp switch was often placed in an awkward position. Further, an overly rigid stylet could cause retraction of the ETT out of the glottis when the lightwand was withdrawn.[2] Newer models have improved upon the visibility of the light, as well as the ergonomics of the device.[5] The Trachlight (Laerdal, Long Beach, CA), with its three-piece retractable wire lighted stylet, facilitates advancement of the lightwand-ETT and makes it unlikely that the ETT will be withdrawn from the trachea when the Trachlight device is pulled back. A locking device for the proximal portion of the ETT, and an adjustable length to accommodate different size tubes, also represent significant improvements of the Trachlight over earlier lighted stylets.[5]

Evidence

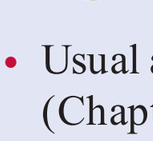
In the operating room (OR), lighted stylet intubation has proven reliable and highly successful in both adults and children, in routine airway management and difficult airways.[6] Yamamoto[7] suggested in his study of inexperienced intubators that approximately 30 intubations are required to become adept with the use of lighted stylet technique. Ainsworth[4] described intubation using the lighted stylet within 60 seconds in 200 patients under general anesthesia, whereas Weis[8] reported a series of 250 patients in whom he had 99% success in intubation using this device. In 950 surgical patients, use of the Trachlight was compared with direct laryngoscopy for efficacy in tracheal intubation.[5] Direct laryngoscopy was found to require more time, produce more complications, and result in a higher failure rate (3% vs. 1%). In addition, Tsutsui[9] found in a series of 305 patients that lighted stylet intubation with the Trachlight resulted in less of a blood pressure response as compared with direct laryngoscopy. In 186 documented difficult airway patients, Hung[10] used the Trachlight lighted stylet for intubation after induction of anesthesia with 99% success. In 2009, 60 patients with high Mallampati score were studied by Rhee et al in a prospective randomized comparison of lighted stylet and direct laryngoscopy intubation techniques. The authors demonstrated shorter intubation times and a higher first attempt success rate as well as smaller alterations in blood pressure in the lighted stylet group as compared with the direct laryngoscopy group.[11]

In the emergency department (ED), lighted stylets have also proven useful for airway management in facial trauma and appear to facilitate intubation while preserving immobility of the cervical spine.[12,13] In a series of 28 trauma patients with suspected cervical spine injury, the lightwand was employed for intubation with 100% success.[14] The device has been adapted for nasotracheal intubation as well as orotracheal use.[12,15] In prehospital care, Vollmer[3] reported the use of the lighted stylet by emergency medicine residents in 24 patients with 88% success in less than 45 seconds.

The lightwand has been recommended for use in patients with known or potential cervical spine injury, as its use requires little or no motion of the cervical spine. Turkstra et al[16] evaluated cervical spine motion

fluoroscopically in a crossover study of 36 healthy patients undergoing intubation with in-line immobilization. The authors compared the lighted stylet with intubation with the MacIntosh laryngoscope blade or use of a stylet during direct laryngoscopy and found the least cervical spine motion occurred with the use of the lighted stylet for intubation. In addition, Konishi et al[11] also demonstrated less cervical spine movement radiographically in 20 ASA 1 and 2 patients while using the lighted stylet intubation as compared with conventional laryngoscopy. Inoue et al randomized 148 patients undergoing intubation during general anesthesia, with in-line immobilization of the cervical spine, to intubation with the lighted stylet or with the intubating laryngeal mask airway (LMA). The authors reported a 97% success with the Trachlight lightwand (Laerdal), versus 73% for the intubating LMA, and concluded that the lightwand was more advantageous for orotracheal intubation in a population with known or potential cervical spine disorders.[17]

The importance of the "bent length" (site of bending of the lighted stylet into a "hockey stick" shape) has recently been evaluated.[18] Chen et al[19] evaluated recommendations that the Trachlight device should optimally be bent 6.5 cm to 8.5 cm proximal to its distal tip. Based on clinical practice, the authors relate the optimal bent length to be the thyromental distance (TMD), that between the patient's thyroid cartilage prominence and the angle of the mandible. They report that for patients with TMD greater than 5.5 cm, the existing recommendations work well to optimize intubation success with the Trachlight device. However, for smaller patients, with TMD ≤5.5 cm, a bent length at the lower range of the recommendation (6.5 cm) should be used.



Preparation

- Usual arrangements for orotracheal intubation (Fig. 20-1) (Chapter 5)
- Lightwand prepared, lubricated, battery checked
- Thread ETT over wand, until the distal tip with light bulb is at the end of the endotracheal tube (but not protruding)
- Ensure the proximal end of the ETT is held by the locking mechanism of the stylet, so that it does not slide up and down
- Bend the lightwand-ETT into a "field hockey stick" configuration (90° to 120° bend proximal to cuff), 6.5 cm to 8.5 cm proximal to the tip of the lightwand
- Anesthetized, preoxygenated patient, with airway reflexes controlled
- Head in neutral position
- Placing the illuminated stylet on the inside of the patient's cheek approximates the halo of light sought with laryngeal transillumination
- Stand at the head of the patient



Procedure for Lightwand (Figs. 20-2–20-8 and 20-11)

- Grasp/advance the mandible with the nondominant hand
- Insert lighted stylet (with light on) over back of tongue
- Make attempts to advance into glottis, searching for opening by gently advancing the tube/stylet repeatedly toward the larynx in a "rocking" motion
- If resistance is met, head extension, or jaw thrust may be helpful to facilitate glottic entry
- Halo of light over larynx confirms glottic entry
- Lack of halo, or halo in wrong site, provides cues to location of lightwand-ETT
- When halo appears, advance the ETT, holding stylet in place
- If transillumination cannot be visualized in larynx, consider reducing ambient light
- Remove stylet *while holding ETT*, inflate ETT cuff, confirm ETT placement (see PHOTO)



Procedure for Trachlight Device (Figs. 20-9 and 20-10)

- With Trachlight device, enter glottis in same fashion (using transillumination)
- Retract wire stylet upon glottic entry
- Advance tube and Trachlight further into the glottis, until transillumination is noted in the lower neck, to level of sternal notch

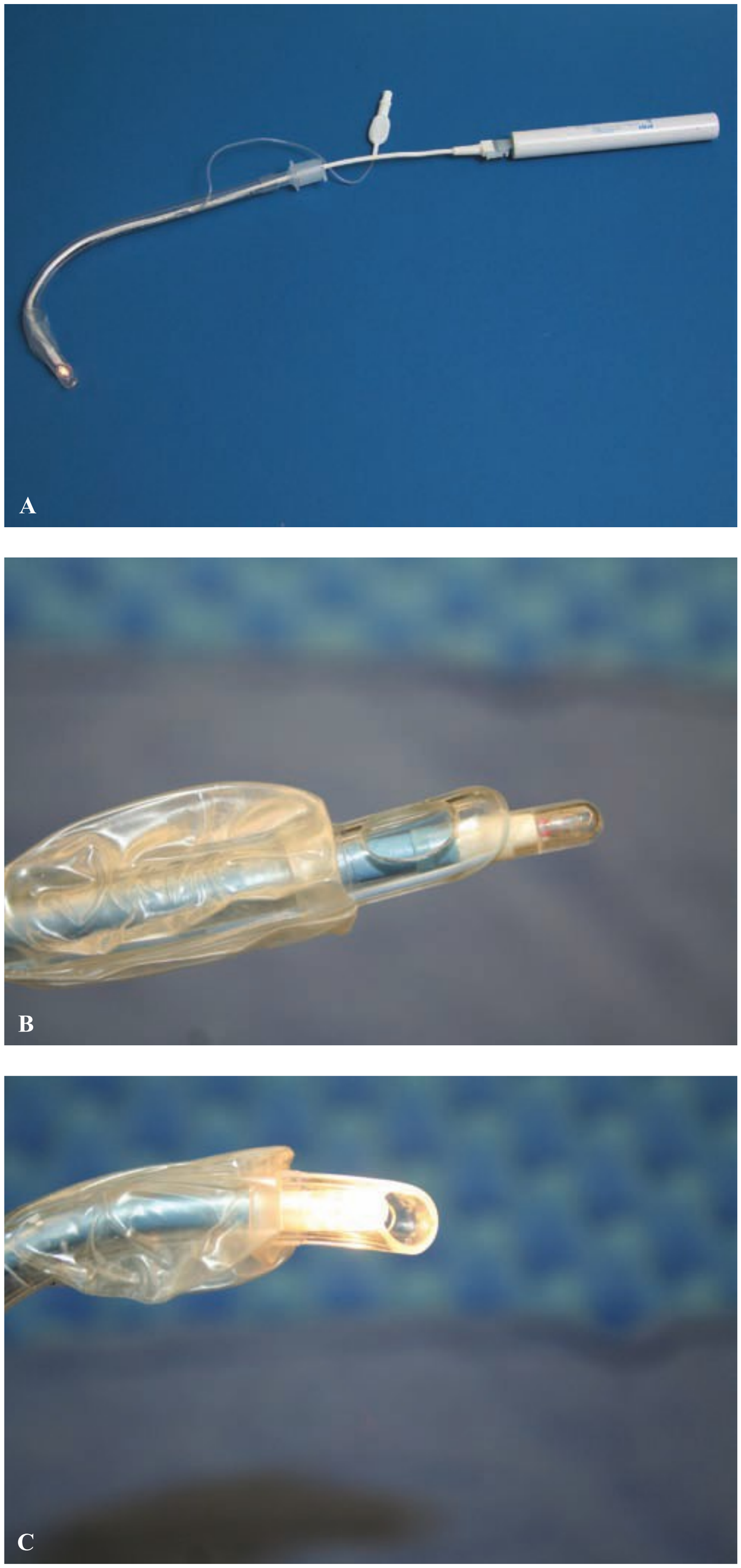


FIGURE 20-1 A. Lighted stylet with ET Tube, and B, close up of tip showing incorrect position with stylet inserted beyond tip of ET tube. In C, the correct position of the stylet in ET tube is shown.

FIGURE 20-2 Insertion of lightwand-ETT into oropharynx in cadaver specimen.

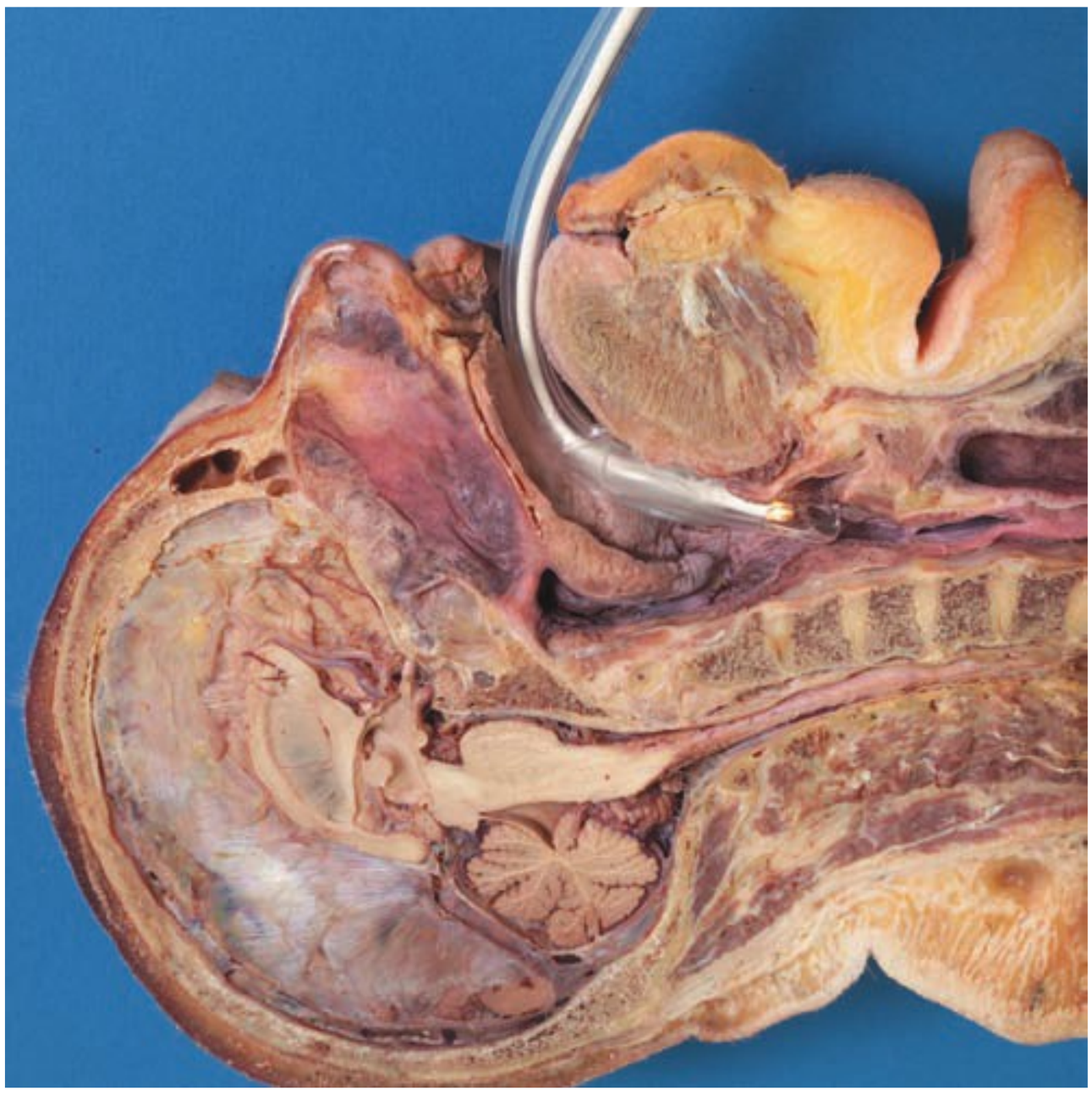
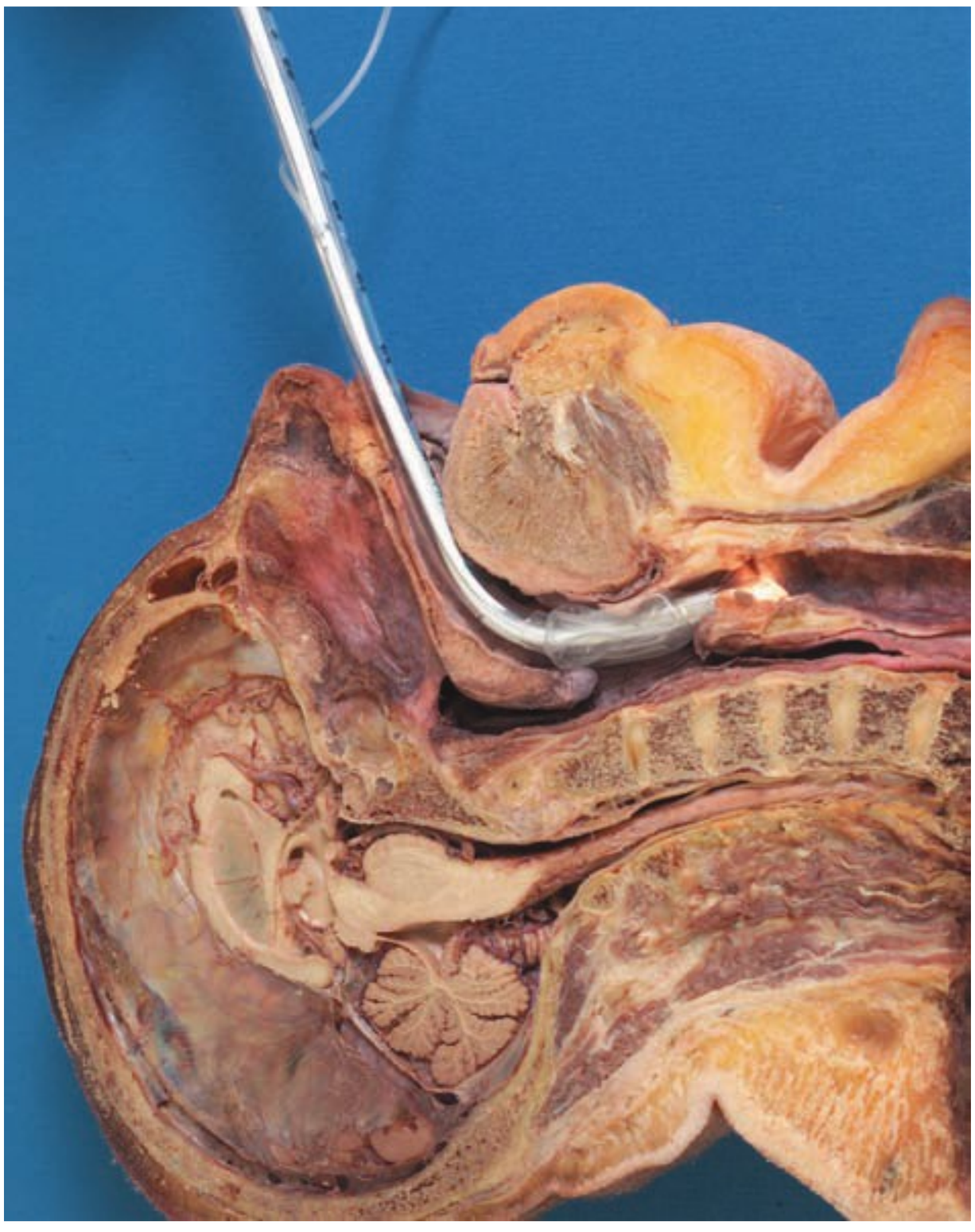


FIGURE 20-3 Lightwand-ETT approaching glottis.



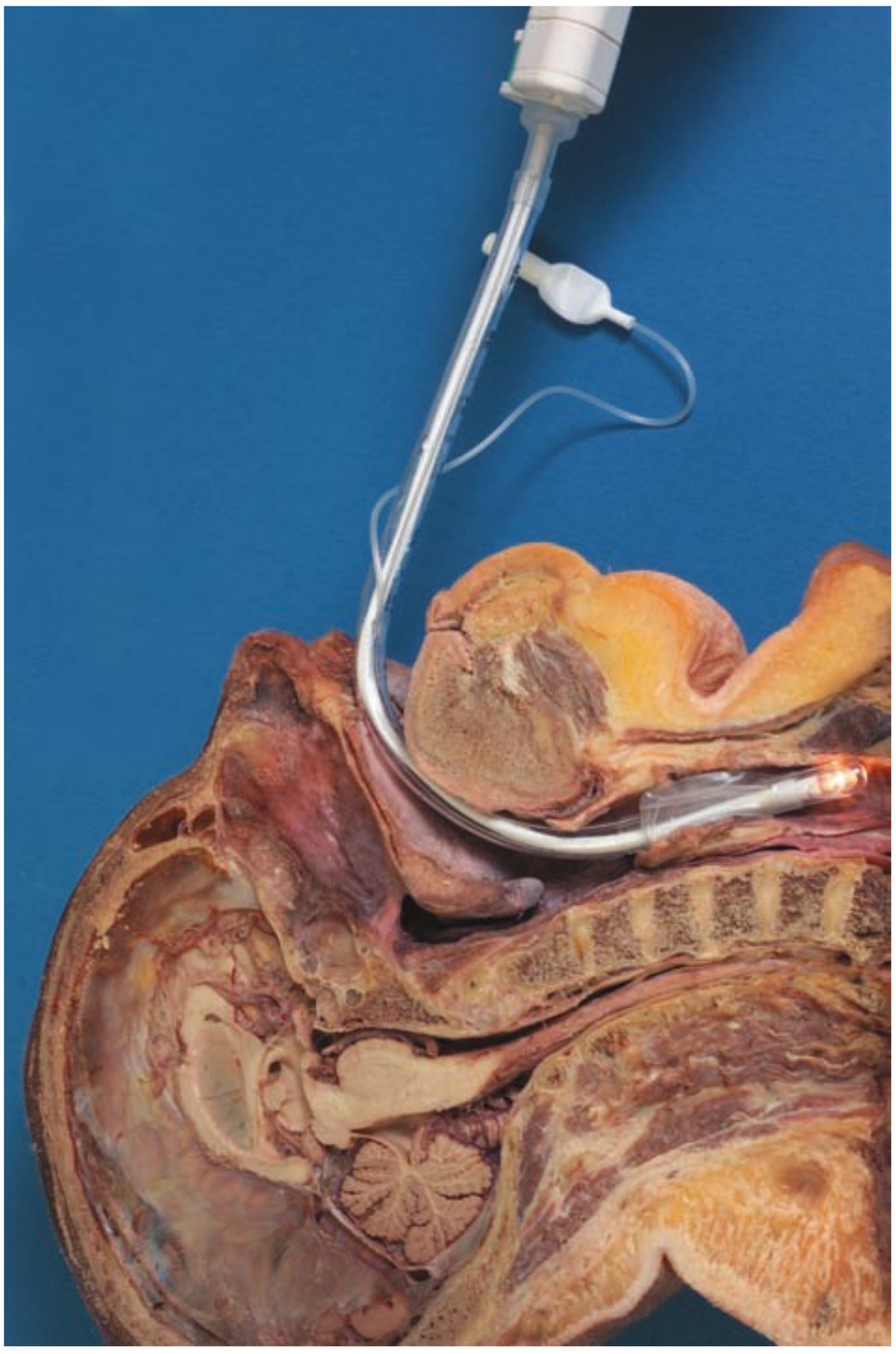


FIGURE 20-4 Lightwand-ETT advanced into airway.



FIGURE 20-5 Insertion of lightwand-ETT.



FIGURE 20-6 The lightwand is advanced into the hypopharynx.



FIGURE 20-7 **A, B, C:** Halo of light produced by lightwand-ETT in both sides of esophagus, and in larynx.



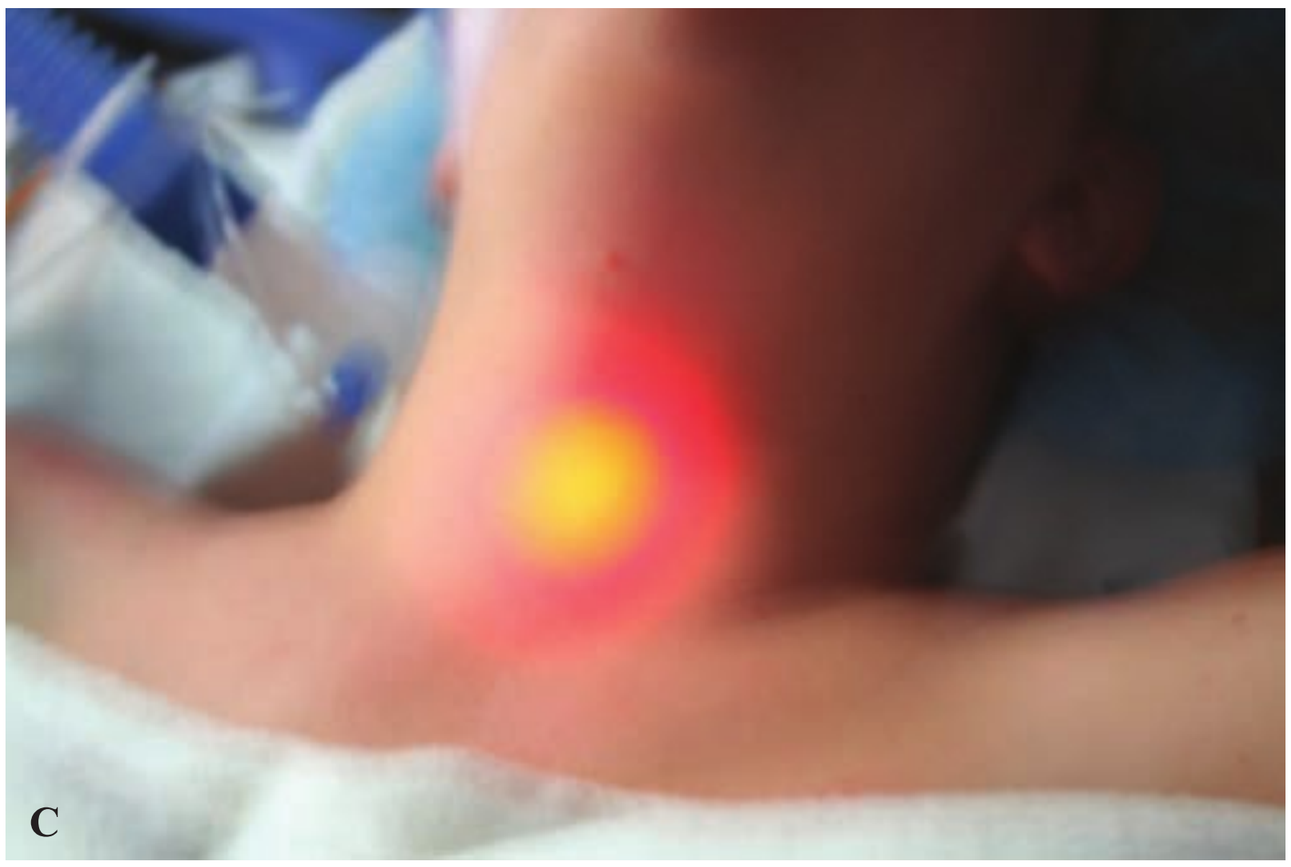


FIGURE 20-7 (Continued)





FIGURE 20-8 **A and B:** A "rocking" motion is made with the lightwand to facilitate glottic entry.

FIGURE 20-9 Trachlight: ETT loaded, locked into position.

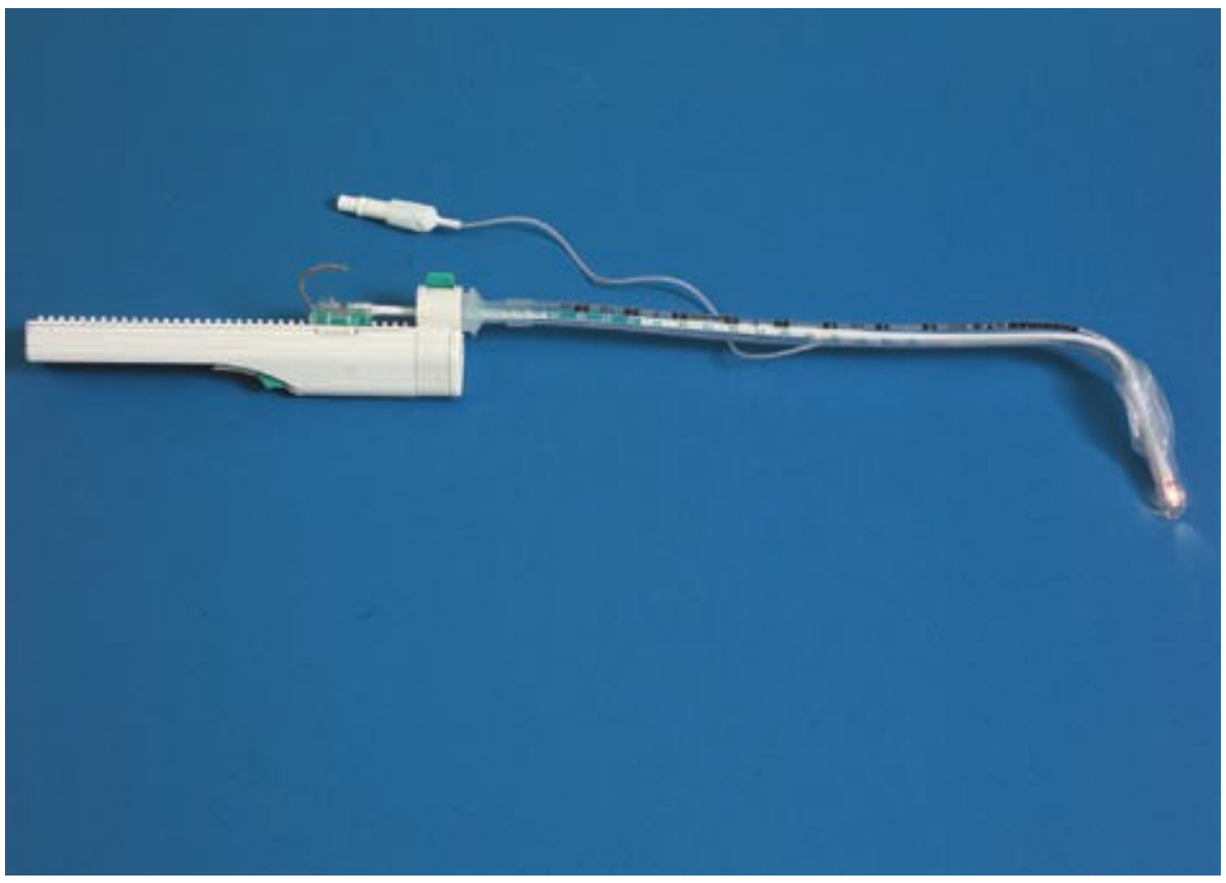


FIGURE 20-10 Trachlight: insertion of ETT into pharynx.



- Unlock the collar around the ETT adaptor
- Advance the ETT off the stylet
- Grasp the ETT firmly
- Remove the stylet, inflate ETT cuff, confirm tube placement

Practicality

- Simple, portable
- Trachlight is more complex; requires some practice and familiarity with its components
- **Affordable: the usual lightwand is $35 and the Trachlight is $80**
- Not a familiar technique; requires some training
- Older models produce a poor halo and require a dark room
- Very obese patients may render this technique ineffectual

Indications

- Difficult laryngoscopy
- Copious secretions or blood in airway
- Routine intubation
- Potential or known cervical spine injury in patient requiring airway management



FIGURE 20-11 Removal of stylet from ETT.

Contraindications

- Laryngeal trauma
- Hypoxic patient who cannot be ventilated (time prohibits)
- Obstruction or distortion of upper airway anatomy
- Grossly obese patients (body mass index > 30 reduces likelihood of success)
- Insufficient anesthesia/lack of control of airway reflexes

Complications

- Misplaced ETT due to misinterpretation of halo effect
- Inadvertent withdrawal of ETT from larynx when lighted stylet is pulled back
- Inability to see transillumination in obese patients
- Inability to advance ETT despite transillumination
- Trauma to larynx or pharynx from blind probing
- Regurgitation/aspiration
- Hoarseness

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CHAPTER 21

Optical Stylets

Stephen Esper and Steve Orebaugh

Concept

Through the use of fiberoptic light and image bundles, optical stylets permit the user to obtain a view from the distal end of the endotracheal tube (ETT). The stylets allow direct visualization of structures at the tip of the tube as it is inserted, simplifying intubation when a poor laryngoscopic grade is encountered and facilitating confirmation of tube placement (Figs. 21-1–21-4). Because of the bright light at the tip of the device, the optical stylet can also act as a lightwand if visualization through the optics is poor. These devices require the operator to look through an objective lens as the device is inserted into the airway. Optical stylets are frequently used in conjunction with direct laryngoscopy, or a jaw thrust, elevating the mandible and tongue for optimum visualization. In essence, this is a simpler and less expensive version of the fiberoptic intubating bronchoscope.

Types of Stylets

There are multiple types of optical stylets in use. Some of the most common include the Shikani Optical Stylet, the Levitan (First Pass Success or FPS) Optical Stylet, and the Bonfils Retromolar Intubation Fiberscope. These optical stylets are used in different situations and the insertion technique differs among the classes.

The Shikani Optical Stylet (Clarus Medical, Minneapolis, MN), like the lighted stylet and the other optical stylets discussed below may be used for routine airway management. In addition, this device is useful for situations in which a difficult airway is anticipated or in urgent situations when a patient presents an unanticipated challenging or difficult airway (as long as ventilation is successful and the patient is not hypoxemic).Referred to as a "seeing bougie," the Shikani stylet is a malleable device that is able to conform to the patient's airway.

The Levitan FPS Optical Stylet (Clarus Medical, Minneapolis, MN) is a device that is intended for use in concert with direct laryngoscopy, when little or none of the glottic opening can be visualized. It has a shorter tube length to allow the ETT to be fitted directly to the device without the need for a tube stop and requires cutting off the ETT to 28 cm in order to fit onto the stylet. This short length facilitates ready positioning of the device in front of the operator's eye during the process of direct laryngoscopy when a challenging view is evident. There is a site for an oxygen connector to insufflate oxygen. Lightwand-like transillumination is also available as well.

The Bonfils Retromolar Intubation Fiberscope (Karl Storz Endoscopy, CA) was derived from the work of Bonfils[1] in which he described an approach from a very lateral position, behind the molar teeth, to intubate children with Pierre Robin syndrome. The device is a traditional rigid optical stylet with a fixed 40° angulation at the distal end, which can be illuminated by either a remote or attachable (battery-powered) Xenon light source. The smallest version allows placement of a 4.0 mm internal diameter ETT.

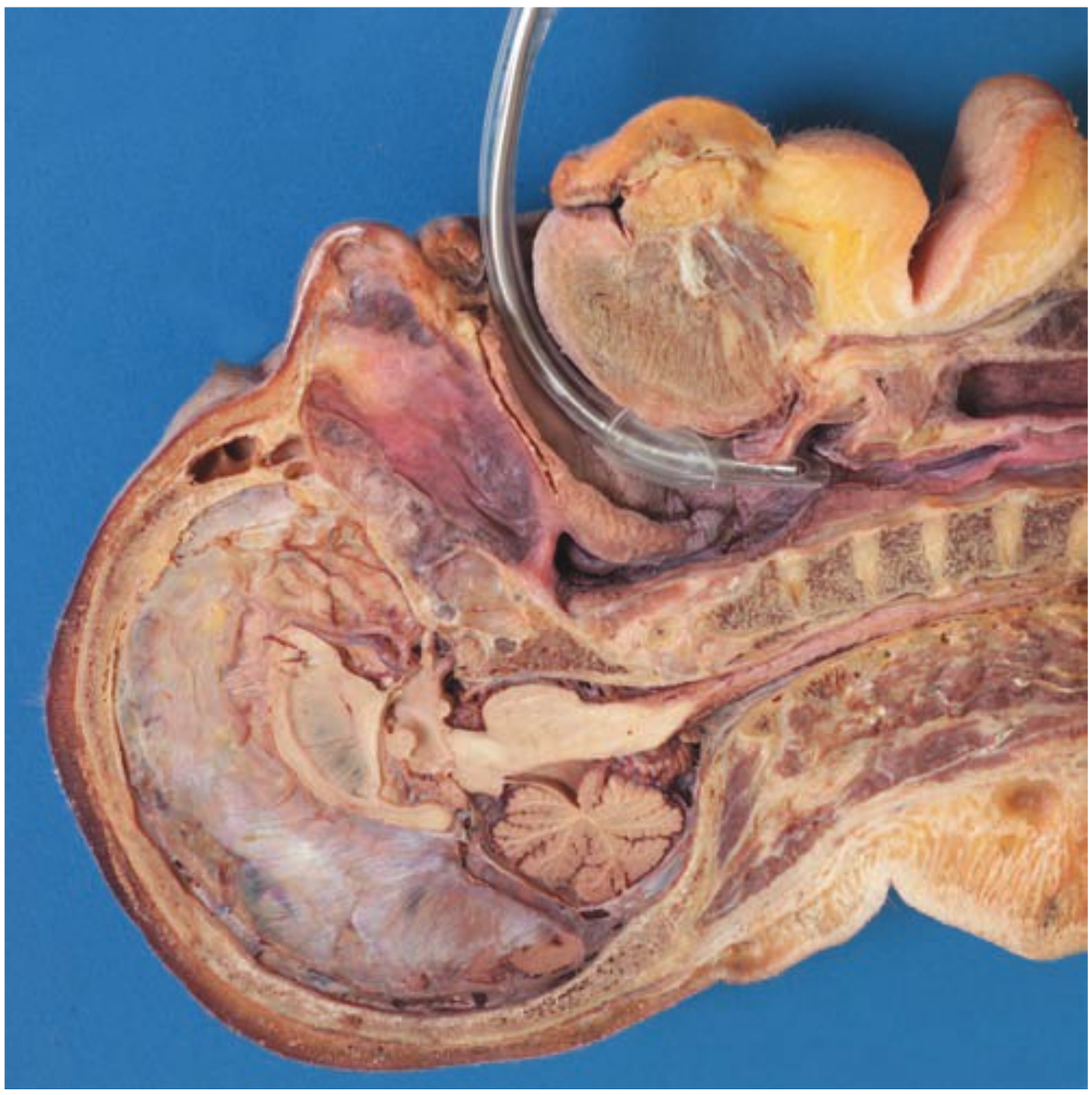
Another device, the Sensascope (Acutronic MS, Hirzel, Switzerland), combines some features of an optical stylet and a fiberoptic scope. The Sensascope has a rigid, S-shaped shaft that is 6 mm in diameter, with a distal, 3-cm steerable tip, as well as a built-in camera and LED light source. The image is displayed on a separate video monitor, rather than observed through an eyepiece. For optimal function, the device is recommended to be used with direct laryngoscopy to retract the tongue and soft tissues before insertion into the pharynx.

Some seeing-stylet type devices do not have the rigidity of the above devices but nonetheless allow visualization of the anatomy at the tip of an inserted ETT. The "Pocket Scope" (Clarus Medical, Minneapolis, MN) is a flexible, 42 cm shaft that is 3.3 mm in diameter and which is illuminated by an attachable "green line" laryngoscope handle. The device is used to rapidly confirm the placement of an ETT or a double lumen ETT, with less complexity and expense than a standard fiberscope. Because of its flexibility, it would not be particularly useful for intubation in a difficult airway situation. The Tracheoscopic Ventilation Tube (TVT, ET View, Misgav, Israel) is an ETT, available in sizes 7, 7.5, and 8 mm internal diameter, with a miniature camera and light source imbedded at the distal tip, which connects to a video monitor. It permits ready confirmation of ETT placement and continuous monitoring of ETT position in the airway. In addition, this device facilitates viewing the glottis in the setting of unfavorable anatomy during direct laryngoscopy and, with the maneuverability afforded by a standard stylet in the tube, would permit one to steer the tube more effectively to the glottic opening.

FIGURE 21-1 Shikani Optical Stylet.



FIGURE 21-2 Insertion of optical stylet-ETT behind the tongue in a cadaver specimen.



Evidence

Optical stylets have been used for difficult and routine intubation in the operating room (OR).[2–4] The optical stylet has not been subjected to controlled, comparative studies in the management of the difficult airway. At the same time, in small series, it has proven useful for airway management in the OR. In a study of 32 patients undergoing elective anesthesia for surgery, 94% of cases were intubated successfully on the first attempt and the remainder on the second attempt using this device.[3] Gravenstein[4] compared the fiberoptic stylet with direct laryngoscopy and with bronchoscopic intubation in 75 patients undergoing general anesthesia, evaluating the

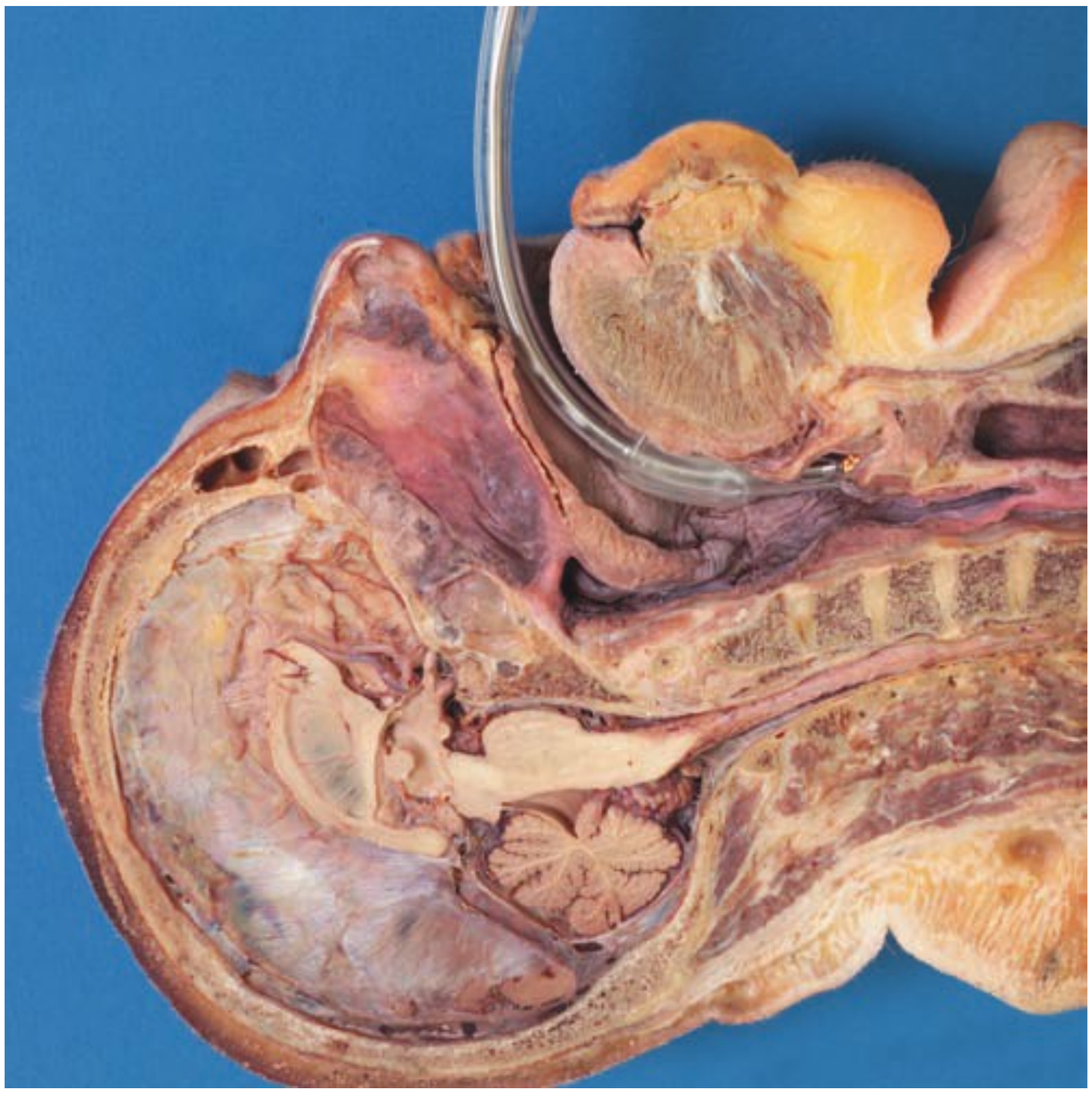


FIGURE 21-3 Optical stylet-ETT advanced to glottis.

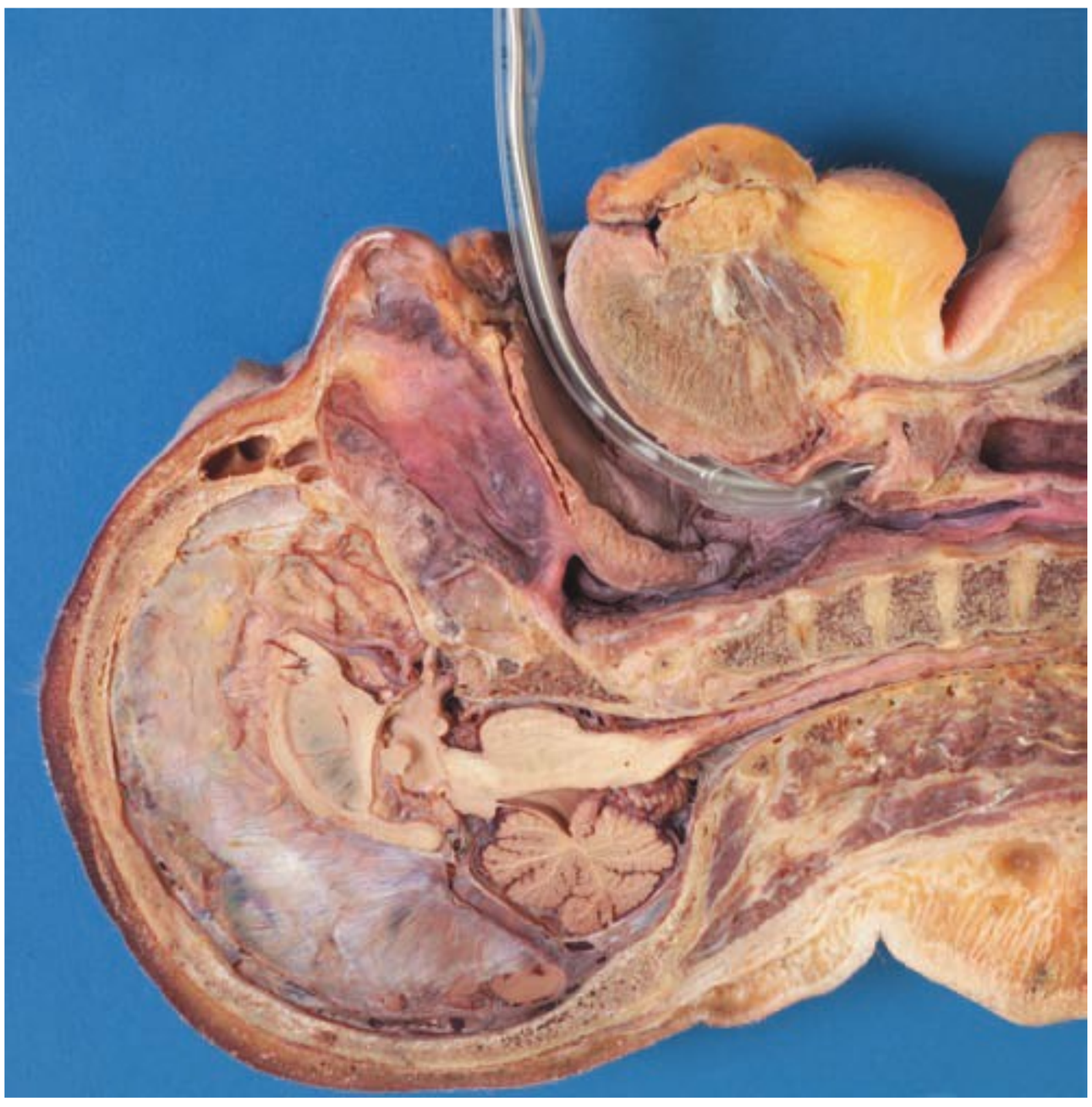


FIGURE 21-4 Tip of optical stylet-ETT placed into larynx.

time required for intubation, the quality of the view of the glottis, and the frequency of complications. The author noted a shorter time for intubation using the fiberoptic stylet than for the bronchoscope and a lower rate of postoperative sore throat than direct laryngoscopy. However, the least favorable laryngoscopic view occurred with the fiberoptic stylet. When compared with intubation with direct laryngoscopy using an Eschmann stylet in simulated grade 3 laryngoscopy in a mannequin model, Biro[5] described 100% success using the fiberoptic intubating stylet in tracheal tube placement by 45 anesthetists in 225 intubations, whereas there was a 40% rate of tube misplacement (20% esophageal, 20% endobronchial) using direct laryngoscopy under these circumstances.

Several small series attest to the utility of the optical stylet in children with known, suspected, or simulated difficult airways.[6–8] Weiss et al[6] described use of the optical stylet in 50 pediatric patients undergoing induction of general anesthesia, with a simulated grade 3 laryngoscopy. The intubators were eight nurse anesthetists without prior experience with this device. The authors reported a 92% success rate (intubation within 60 seconds) in this population. In 2006, Evans et al compared an optical style versus gum elastic bougie for intubation in manikins with a difficult airway. Forty-four anesthesiologists assessed Cormack Grade III airways and used both direct laryngoscopy with a gum bougie for tube placement, and an optical stylet. The time to intubation was significantly shorter with the optical stylet. Additionally, esophageal intubation was much less frequent with the optical stylet.[9] Turkstra et al published a crossover randomized controlled trial with 24 patients comparing fluoroscopic evidence of cervical spine motion during intubation using either the optical stylet or MacIntosh laryngoscope. The optical stylet (OS) produced less cervical spine motion than direct laryngoscopy, but this must be weighed against the higher failure rate with the OS and the increased time required for intubation with this device OS (OS:28 +/− 17 seconds, MacIntosh blade 17+/− 7 seconds).[10] There are multiple case reports, case series, and letters to the editor detailing the successful use of the Shikani or Levitan Stylet to facilitate intubation of patients with a difficult airway in both the pediatric and adult after attempts at direct laryngoscopy had failed.[7,11] In 2009, Paladino et al[12] published a pilot study in sheep detailing the successful and rapid use of the optical stylet for a cricothyroidotomy procedure.

Preparation

- Usual arrangements for orotracheal intubation (see Chapter 5)
- Check optical stylet view through objective (or on video screen)
- Lubricate external surface of stylet
- Apply defogging solution to tip of stylet (or warm it)
- Insert stylet into ETT and configure it into a “hockey stick” shape (Fig. 21-1)
- Anesthetized, or unconscious, preoxygenated patient in neutral position
- Stand at head of patient

Procedure for use of Shikani Optical Stylet (Clarus Medical) (Figs. 21-2–21-8)

- Open mouth, lift mandible with nondominant hand, or control tongue with direct laryngoscopy



FIGURE 21-5 Shikani Stylet with ETT as it is placed in mouth.



FIGURE 21-6 A jaw thrust facilitates visualization of the glottis (direct laryngoscopy may also be used).



FIGURE 21-7 Guiding the tip of the optic stylet into the glottis while visualizing position in the hypopharynx.



FIGURE 21-8 Removal of optic stylet while ETT is firmly grasped and held in place.

- Insert tip of optical stylet at back of tongue in midline
- Establish jaw thrust (with assistant) or provide direct laryngoscopy to move soft tissues off back of pharynx
- View structures at base of tongue/hypopharynx through stylet
- Locate glottic opening
- Advance tip of tube into glottis under direct visualization
- Confirm presence in airway with view of tracheal rings
- Firmly grasp ETT (or have assistant do so)
- Remove stylet device from ETT
- Inflate ETT cuff, confirm ETT position, and fix in place

Practicality

- Simpler than fiberoptic bronchoscope (FOB) intubation
- Expensive, but less so than FOB (approximately $2,000)
- Portable
- Not familiar; requiring practice before use in emergency situation
- Viewing characteristics less favorable than FOB
- Less useful for nasal intubation than FOB

Indications

- Difficult laryngoscopy
- Cervical spine injury, in patient requiring airway management

Contraindications

- Inaccessibility of oral cavity
- Copious secretions or blood in airway
- Upper airway obstruction
- Laryngeal trauma
- Severely hypoxic patient who cannot be ventilated (due to time constraints)

Complications

- Fogging of instrument with reduced view
- Laryngeal or pharyngeal trauma
- Poor visualization/inability to place tube
- Tube misplacement
- Regurgitation/aspiration

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PART VI

Retrograde Techniques

CHAPTER 22

Retrograde Intubation

Ryan D. Ball and David G. Metro

Concept

This invasive technique allows for blind placement of an endotracheal tube (ETT) over a guidewire or catheter that is inserted percutaneously at the level of the cricothyroid membrane (CTM) or cricotracheal ligament. The wire is then directed retrograde up into the pharynx, then into the mouth or nose. The procedure was originally described with the use of a red rubber catheter introduced through a tracheostomy and has evolved to include the use of a guidewire placed percutaneously and pulled retrograde, then placed through the lumen or Murphy eye of the ETT.[1,2] Retrograde intubation (RI) can be performed with just a guidewire. However, because an ETT has the potential to move laterally about a thin wire, and then catch on the aryepiglottic fold or arytenoid cartilage as it is inserted, the technique frequently incorporates a guide catheter placed over a wire before the ETT is inserted.[3] The retrograde wire may also be retracted from the nose, allowing for nasotracheal intubation. RI has been used successfully in pediatric difficult airways as well as those of adults.[2]

Evidence

RI was first described by Butler and Cirullo[4] in 1960 and has since been used effectively in patients with normal to severely traumatized airways. The main benefits of this technique over fiberoptic intubation or the newer video laryngoscopic techniques are that blood or secretions in the pharynx do not detract from successful intubation[1,5] and that the equipment needed is inexpensive and readily available. Although there are commercially available kits for RI, successful implementation of this technique has been described with equipment as simple as a Touhy needle and an epidural catheter.[6] RI has been useful in overcoming difficult airway anatomy in both the emergency department (ED) and the operating room (OR).[7,8] However, the technique has not been widely applied in either setting. Data regarding its application are limited to case reports and case series. RI has been described anecdotally in several difficult airway situations, including management of patients with obstructive sleep apnea, facial trauma/burns, large oral cancers, spinal cord injury, spine and joint disorders, oral infections, pharyngeal edema, angioedema, laryngeal carcinomas, and airway anomalies.[2,9,10] Barriot described its use by emergency physicians in the field, where it was employed successfully in 13 patients with severe maxillofacial trauma who could not be intubated by direct laryngoscopy in the prehospital setting, and in another 6 patients in whom the technique was used electively.[5] Its use has also been described perioperativley when fiberoptic intubation was either not available or not feasible with success in 24 of 24 patients.[6] In the hands of those who use the technique frequently, RI appears to have a high success rate. Of 383 applications described in the literature by 1996, the technique was effective in 98.5% of cases.[2]

A potential complication of RI is failure of the ETT to advance into the trachea after the guidewire and guide catheter are removed. Needle puncture at the cricotracheal ligament, just distal to the cricoid cartilage, increases the length of ETT in the larynx when the wire is removed, increasing the likelihood that advancing the tube into the trachea will be successful.[11] Feeding the guidewire through the Murphy eye, rather than the lumen, of the ETT, can achieve a similar effect.[12] A recent study performed on fresh cadavers evaluated the impact of a modified technique of RI to improve ETT guidance into the trachea.[13] Lenfant et al described the removal of the guide catheter after introduction of the ETT into the larynx, leaving the guidewire and ETT in place. The guide catheter is then threaded through the ETT, alongside the wire, and advanced into the trachea. The wire is removed and the ETT moved further into the airway. The guide catheter is then removed from the proximal end of the ETT. This modification did not require significantly more time to complete but resulted in a substantially lower rate of failure of RI. A similar technique involves passing a bougie through the ETT before removal of the wire.[14]

Preparation for RI using Cook Inc, RI kit (Figs. 22-1 and 22-2)

- Usual arrangements for tracheal intubation (see Chapter 5)
- Open and assemble RI kit (Cook Inc, Bloomington, IN) components
- Palpate and mark cricoid cartilage
- Provide subcutaneous anesthesia with lidocaine (if time allows, and patient can perceive pain)
- Create sterile conditions with skin antiseptic and sterile drapes
- Anesthetize and preoxygenate patient (this technique may also be carried out in the conscious patient, with local anesthetic injection translaryngeally to facilitate ETT passage)
- Place patient in sniffing position with neck hyperextended
- Stand at the patient's side, with nondominant hand stabilizing and palpating the larynx

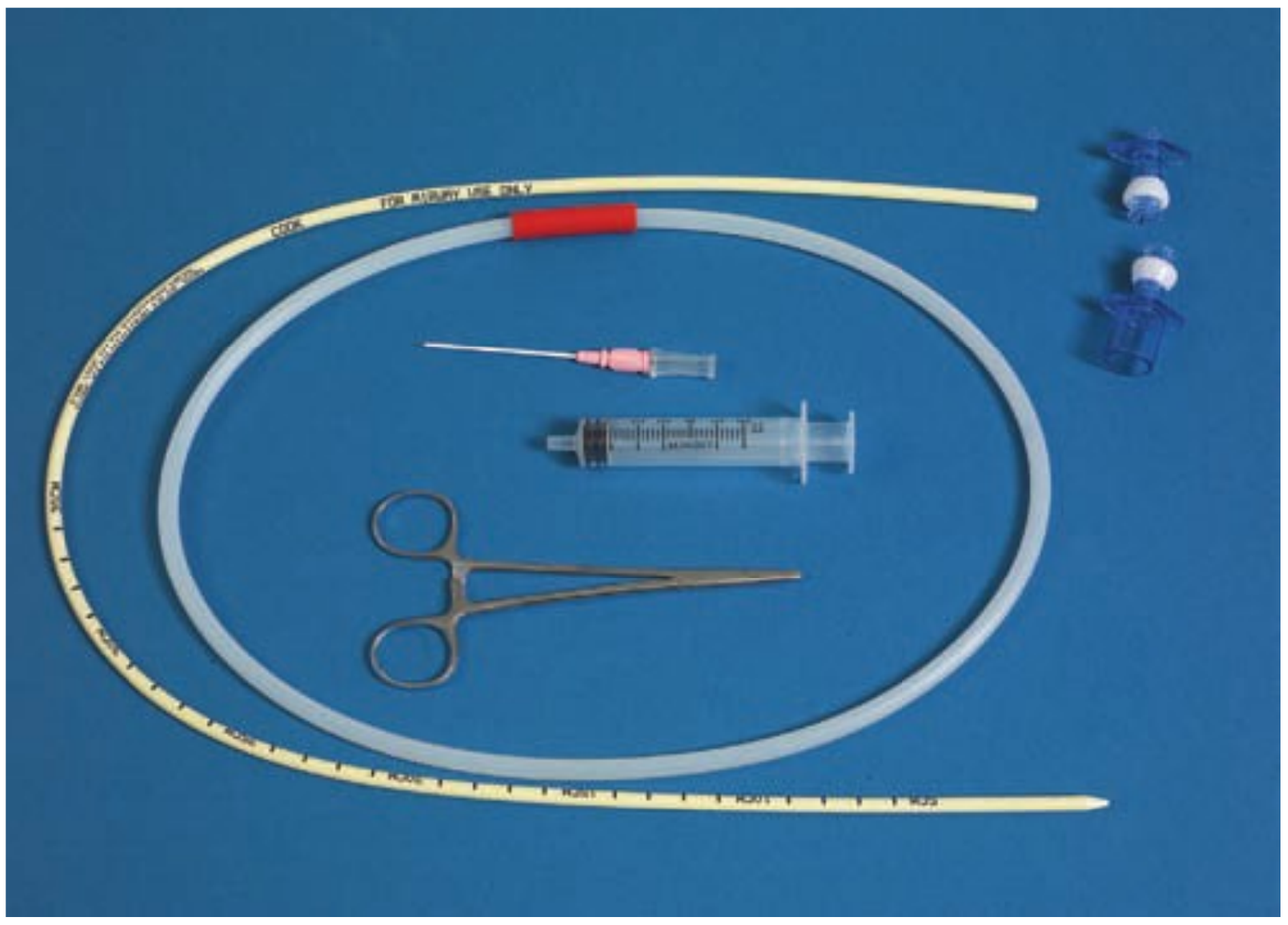


FIGURE 22-1 Components of Cook RI Kit (needle and syringe, wire, guide catheter, hemostat).



FIGURE 22-2 The CTM lies between the cricoid and thyroid cartilages, as indicated here. The needle may also be inserted below the cricoid cartilage, at the cricotracheal ligament, which allows a longer length of ETT to enter the airway before the wire is removed.

Procedure for RI (Oral) (Figs. 22-2–22-13)

- Maintain ventilation and oxygenation throughout the procedure with bag-mask or, if breathing spontaneously, with a nasal cannula or simple face mask
- Aiming 45° cephalad, puncture the CTM with needle/catheter assembly and attached syringe
- The wire may also be introduced inferior to the cricoid cartilage, through the cricotracheal ligament, to increase the amount of the ETT that is in the larynx when the wire is removed



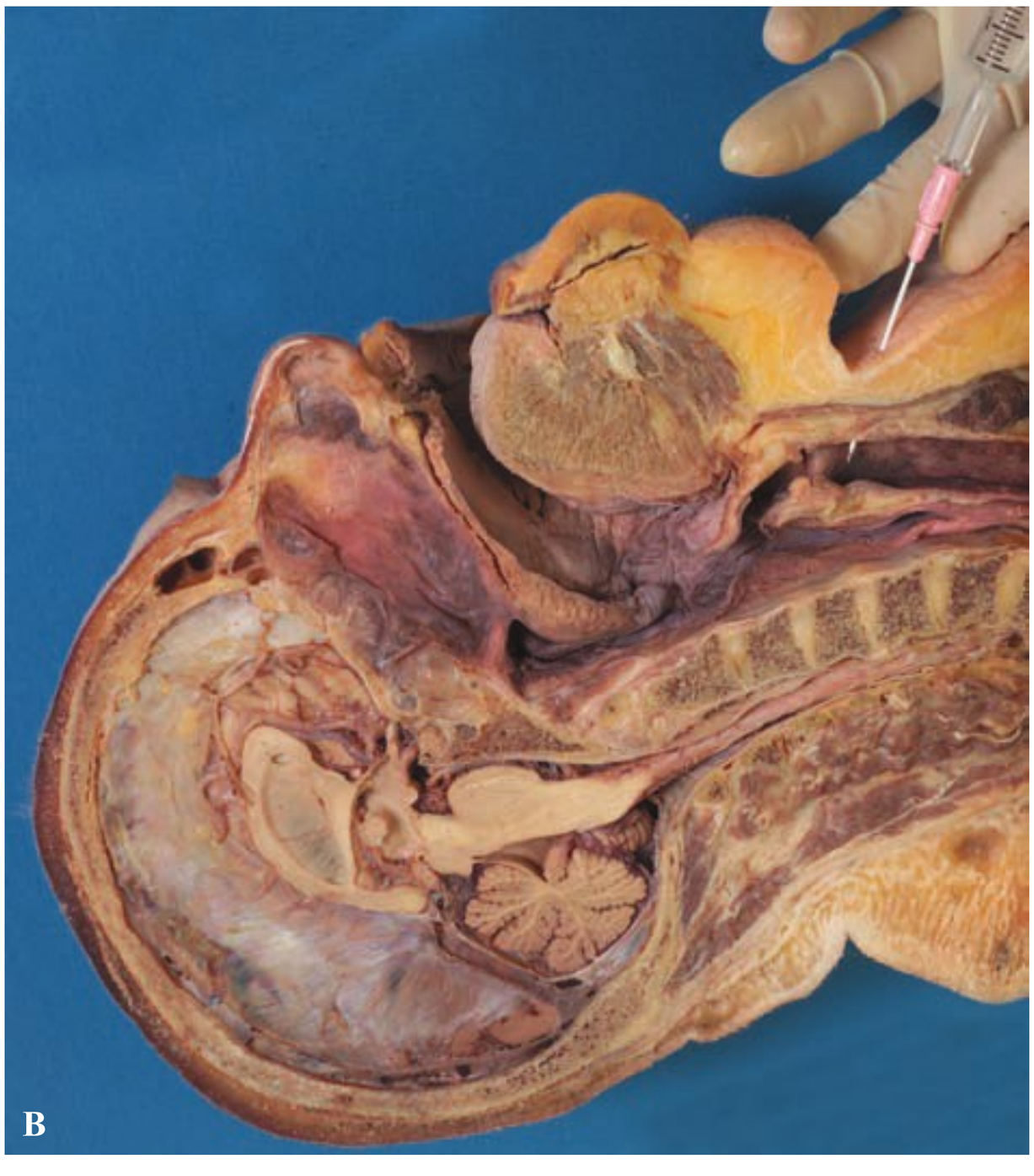


FIGURE 22-3 **A and B:** Needle insertion in CTM.

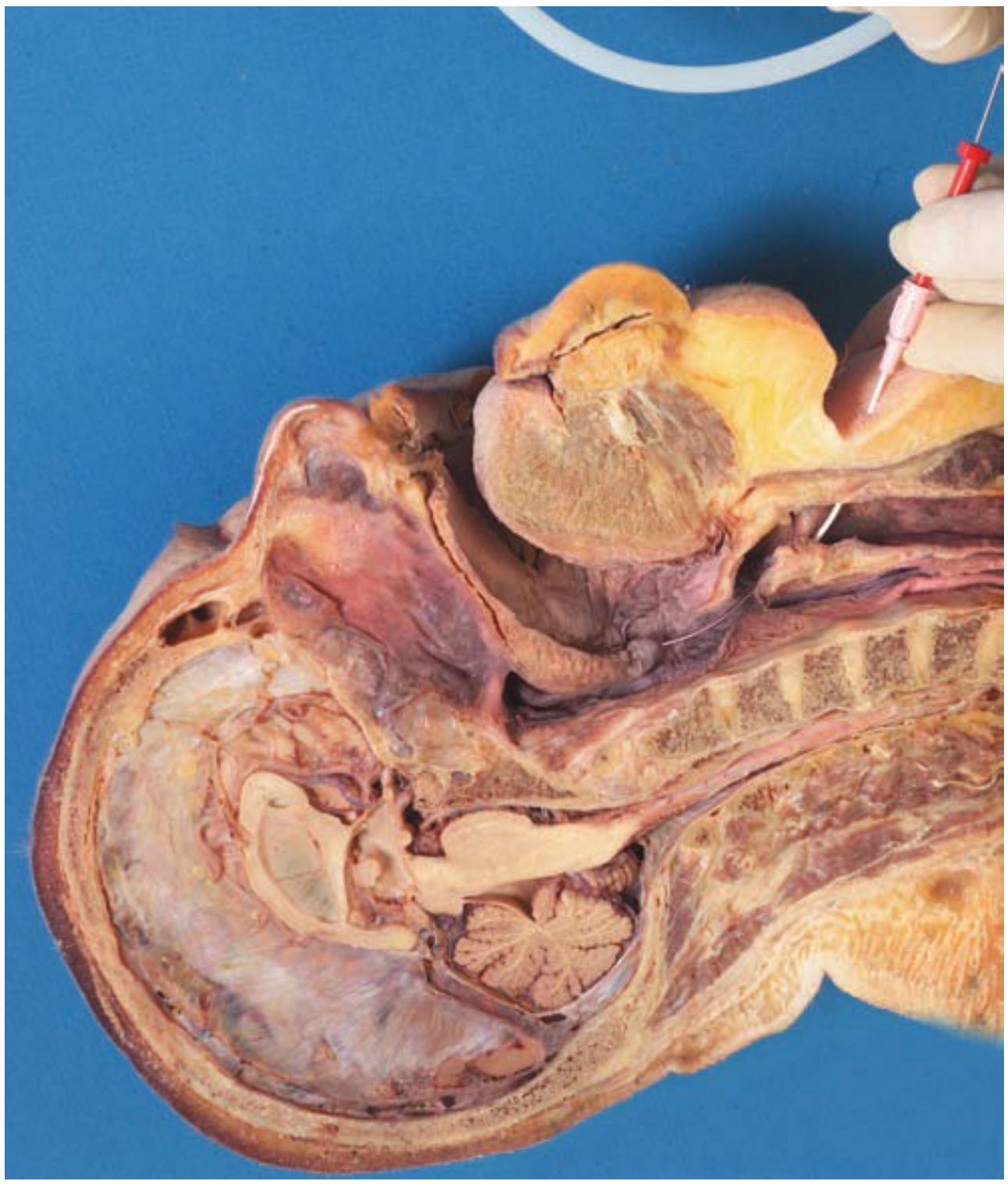


FIGURE 22-4 Wire insertion through thin-walled needle, retrograde into pharynx.

- Confirm needle is in airway by aspirating air into attached syringe
- Remove needle, leaving catheter in airway (confirm presence of catheter in airway by aspirating air freely with syringe)
- Pass wire cephalad into pharynx and into mouth
- Secure wire with hemostat or manually and pull it out of mouth
- Clamp the "tail" of the wire protruding from the CTM, so that it cannot inadvertently enter the airway
- Advance guide catheter over proximal end of the wire, into the mouth and pharynx, until it is palpable at CTM
- Maintain tension on wire, holding both ends (or clamp at entry site into larynx with hemostat)
- As guide catheter enters larynx, the cannula used for wire introduction will be pushed out of the skin at wire entry site—the "turkey timer" method
- Place wire through distal lumen of ETT
- Pass ETT over wire/guide catheter assembly, into pharynx and glottis
- Remove wire/catheter through mouth
- Alternatively, at this stage, remove guide catheter from wire, place it through the ETT alongside wire, and advance into larynx, then remove wire: catheter now acts as stylet to guide ETT past larynx into lower airway (Fig. 22-13)
- Confirm ETT position

Practicality

- Inexpensive
- Portable
- Unfamiliar to most: requires preparation and practice
- Time is an issue: typically requires at least 2 minutes
- Not simple: multiple items are assembled; wires/catheters must slide without kinking or binding; one must identify the entry point correctly; ETT can retract out of larynx when it is advanced, after the wire has been removed

Indications

- Predicted difficult airway
- Copious secretions/blood in airway
- Failure of other intubation techniques (with preserved ability to ventilate)

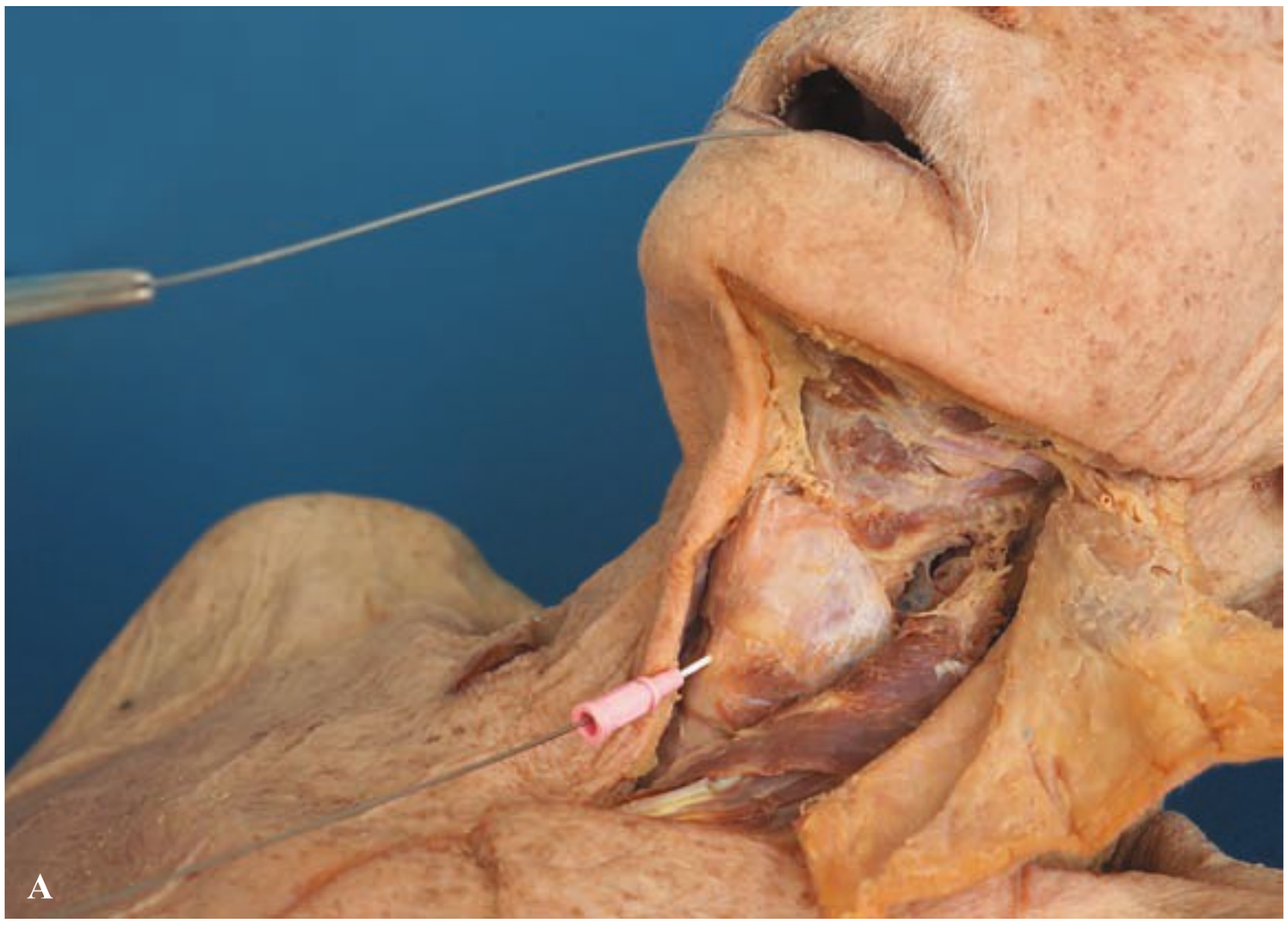
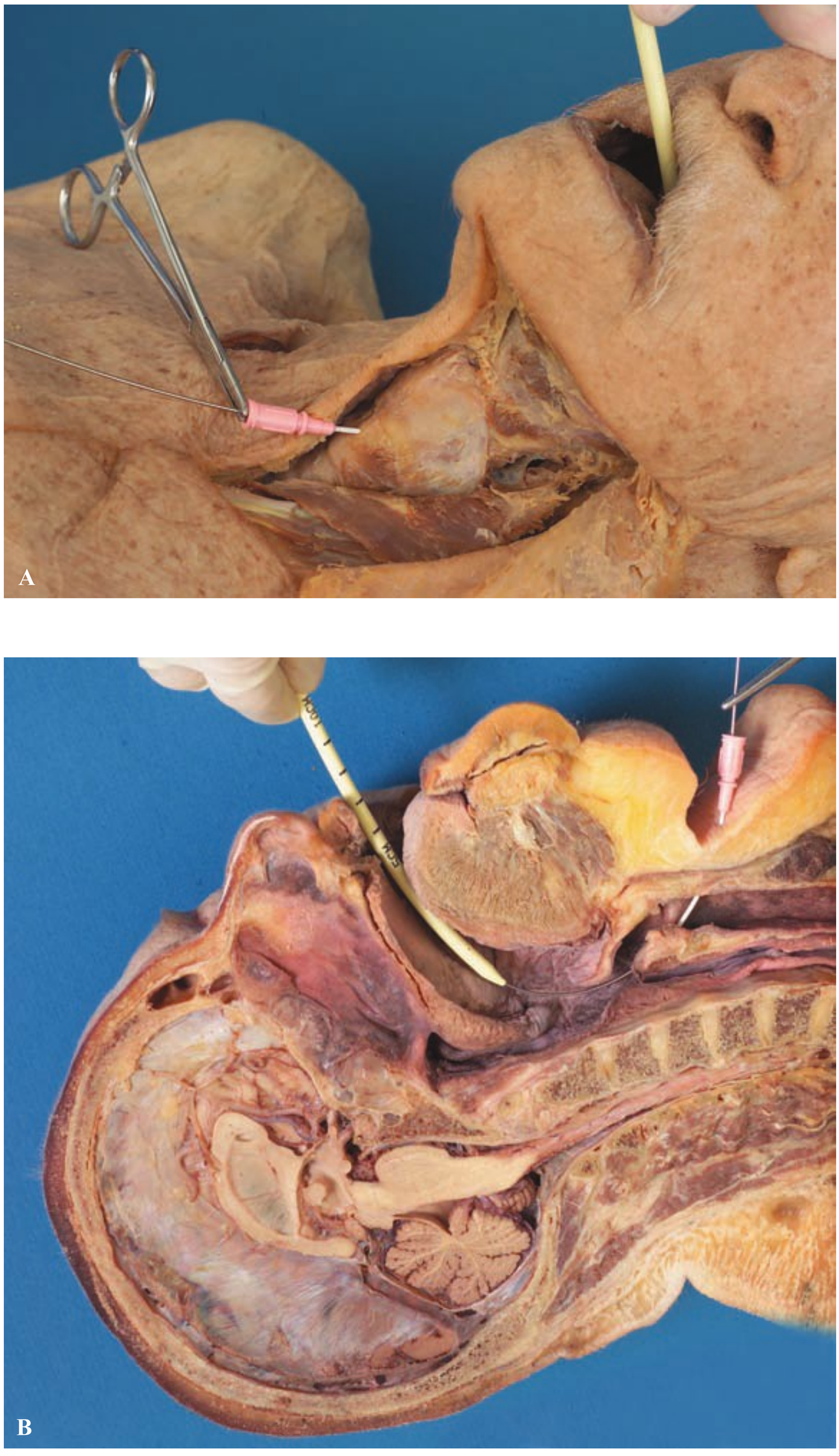




FIGURE 22-5 **A and B:** The wire is grasped with a hemostat and retrieved from the mouth.

FIGURE 22-6 **A and B:** Guide catheter inserted over wire.



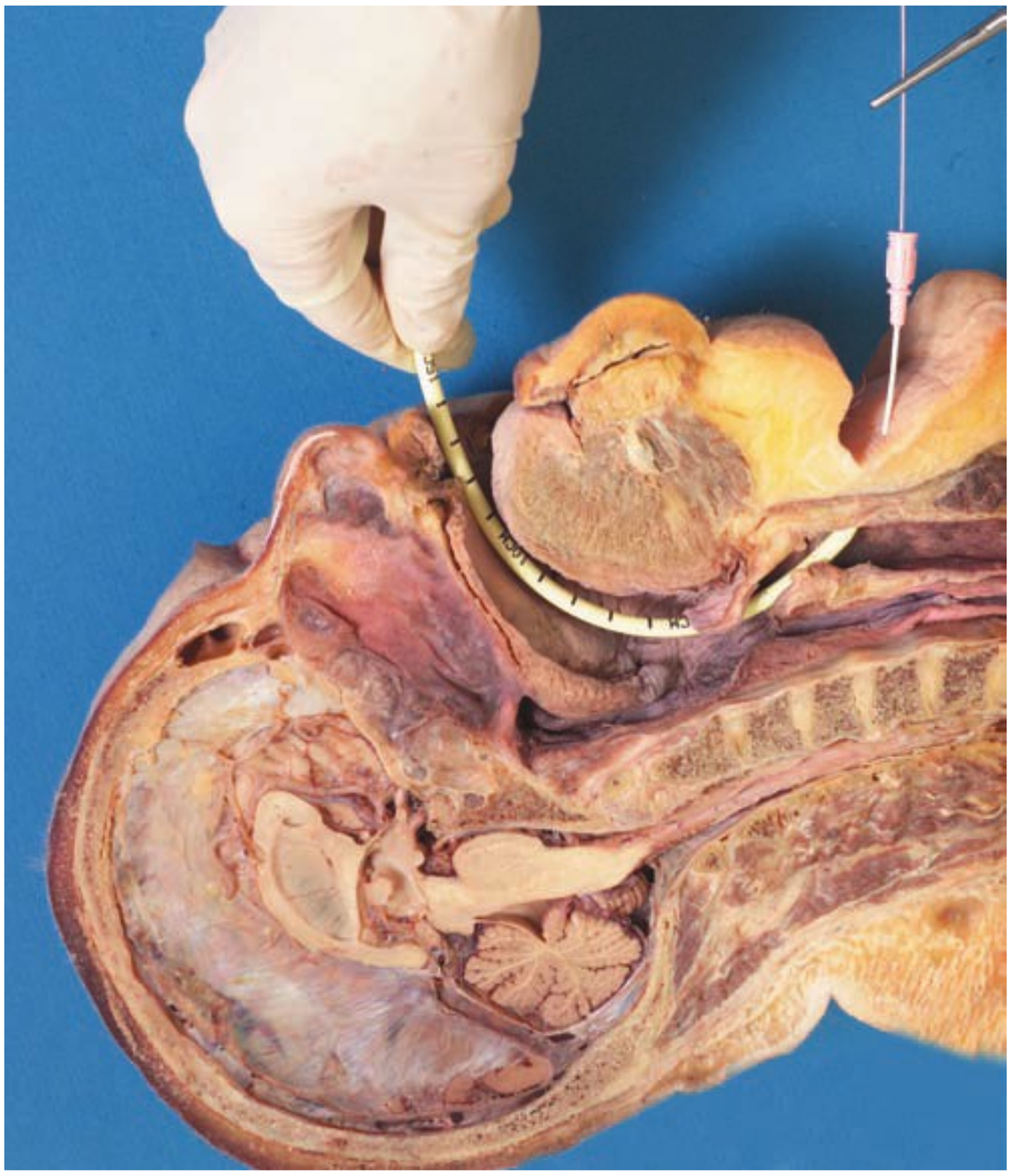


FIGURE 22-7 As guide catheter reaches CTM, the wire-introduction catheter is pushed out of the skin.

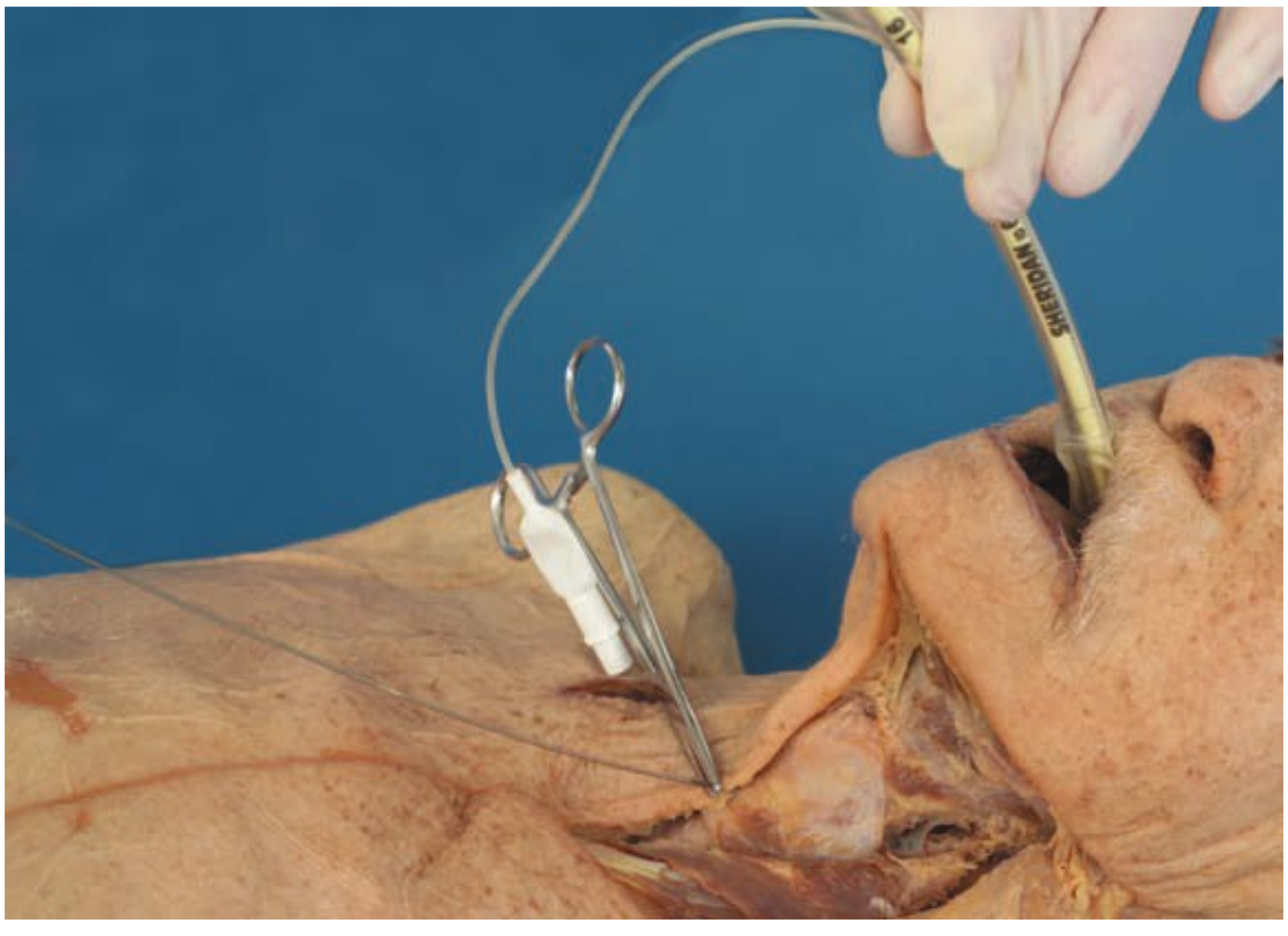


FIGURE 22-8 ETT is now inserted over guide catheter.

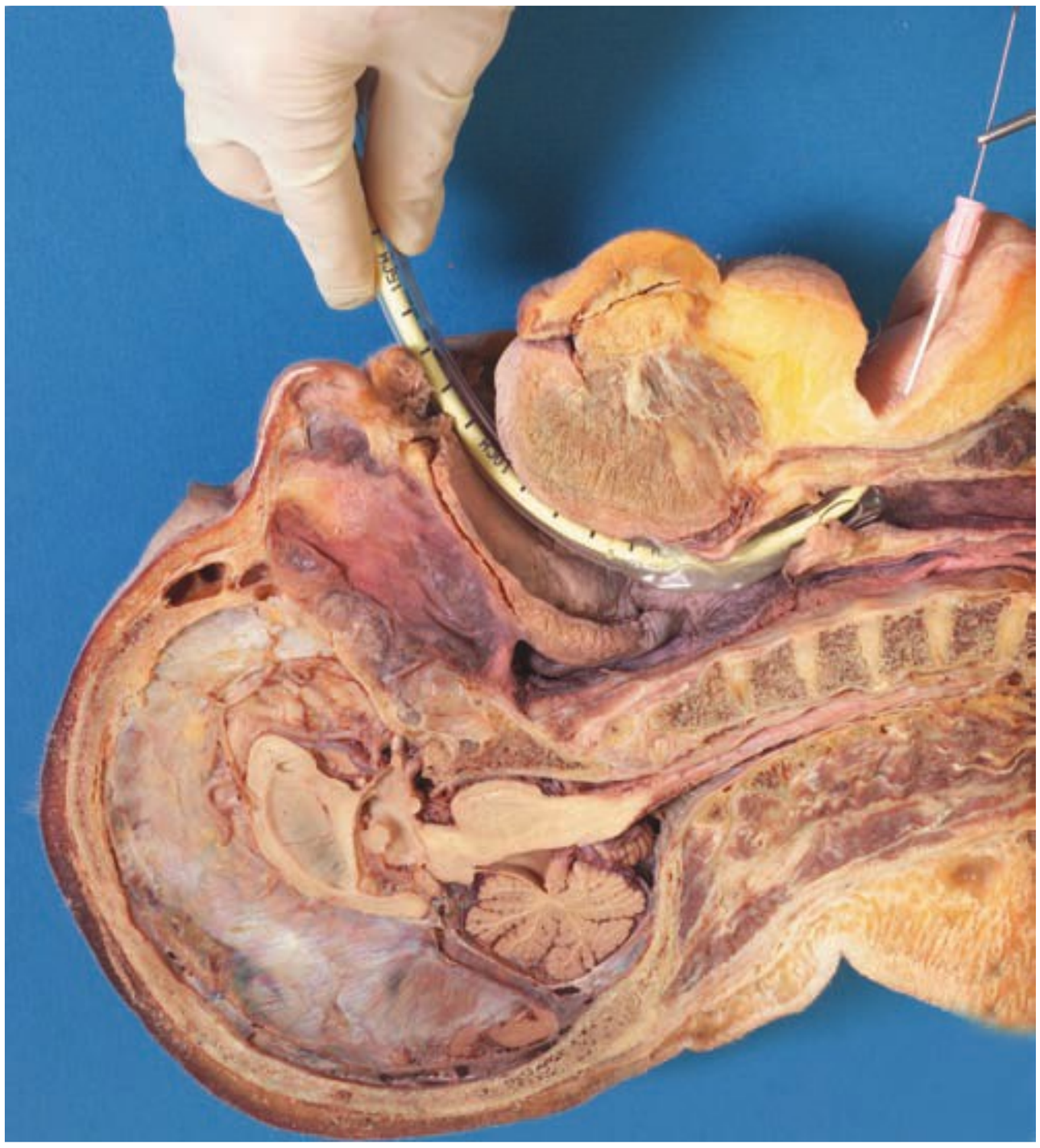


FIGURE 22-9 ETT is advanced along wire/guide catheter, into larynx.



FIGURE 22-10 When the wire is inserted into the distal lumen of the ETT, only a short length of the ETT is in the larynx when it comes to lie up against the CTM (This can lead to ETT displacement out of larynx when wire and guide catheter are removed.).

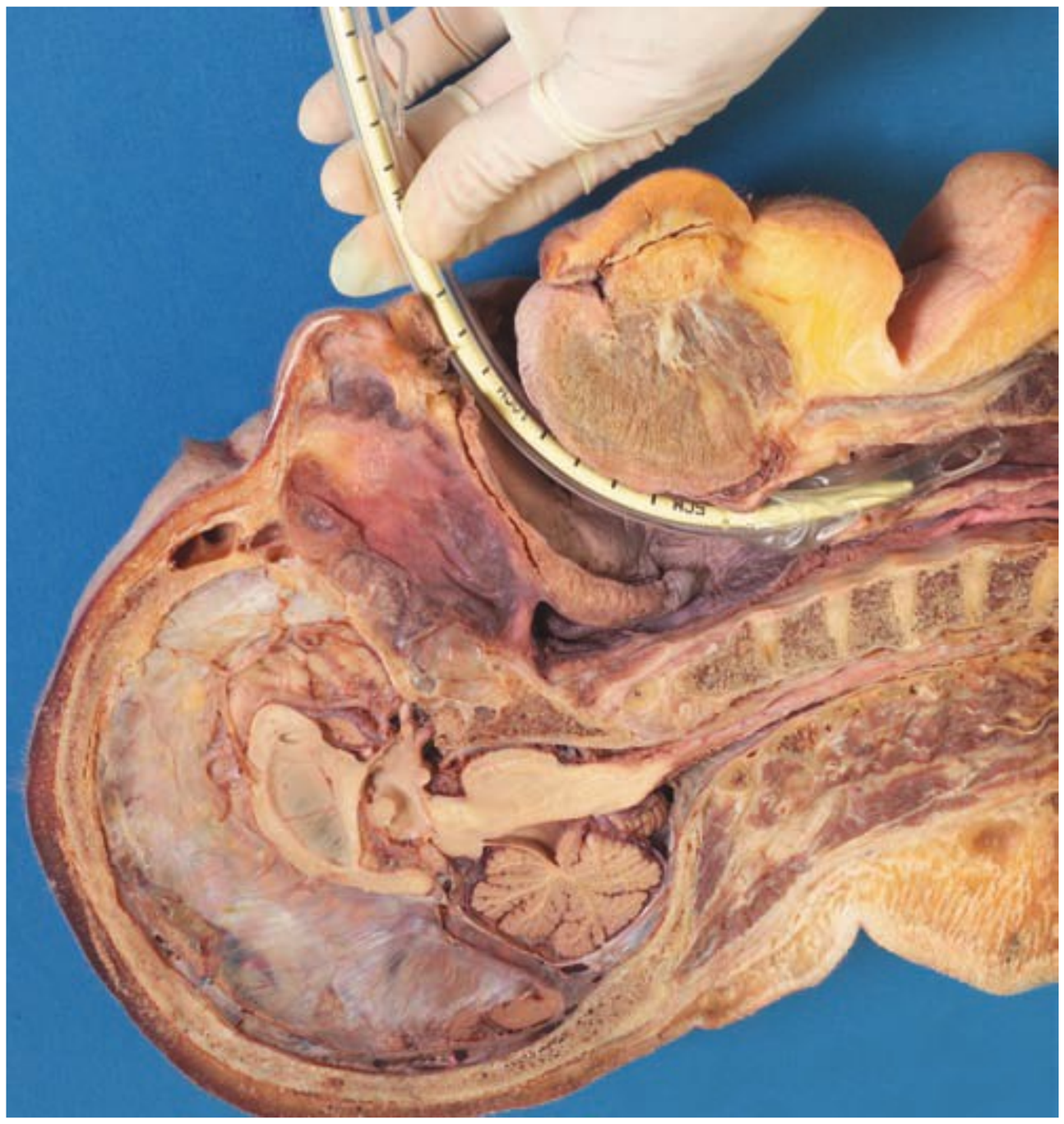


FIGURE 22-11 The wire and guide catheter are removed, leaving the ETT in the larynx.

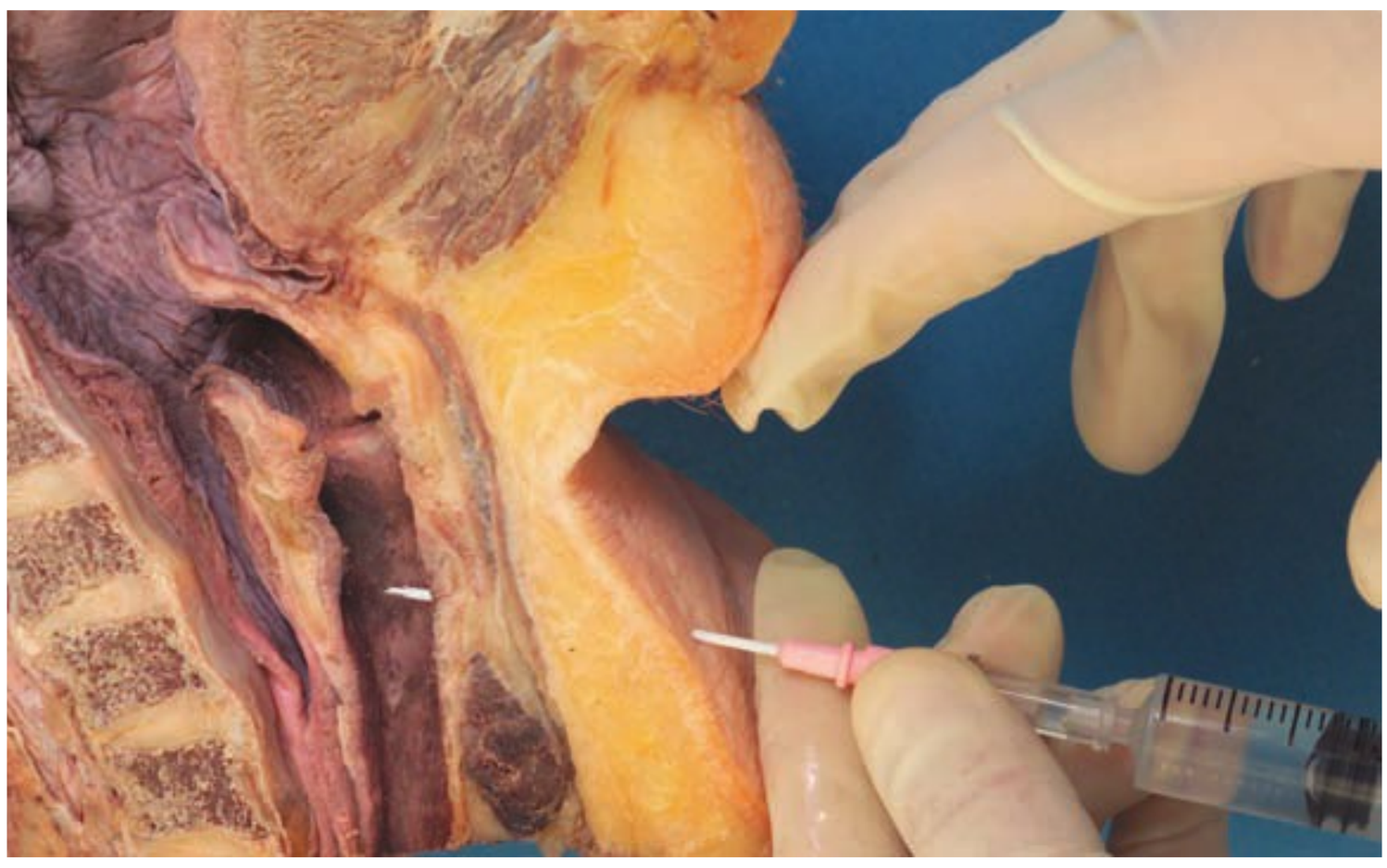


FIGURE 22-12 Insertion of needle at cricotracheal ligament allows a longer length of ETT to be placed into the larynx before wire/guide catheter removal.

Contraindications

- Lack of familiarity with technique
- Laryngeal trauma
- Laryngeal stenosis
- Distorted or unrecognizable neck landmarks
- Bleeding diathesis (relative)
- Severe hypoxia, or inability to ventilate (due to time required)

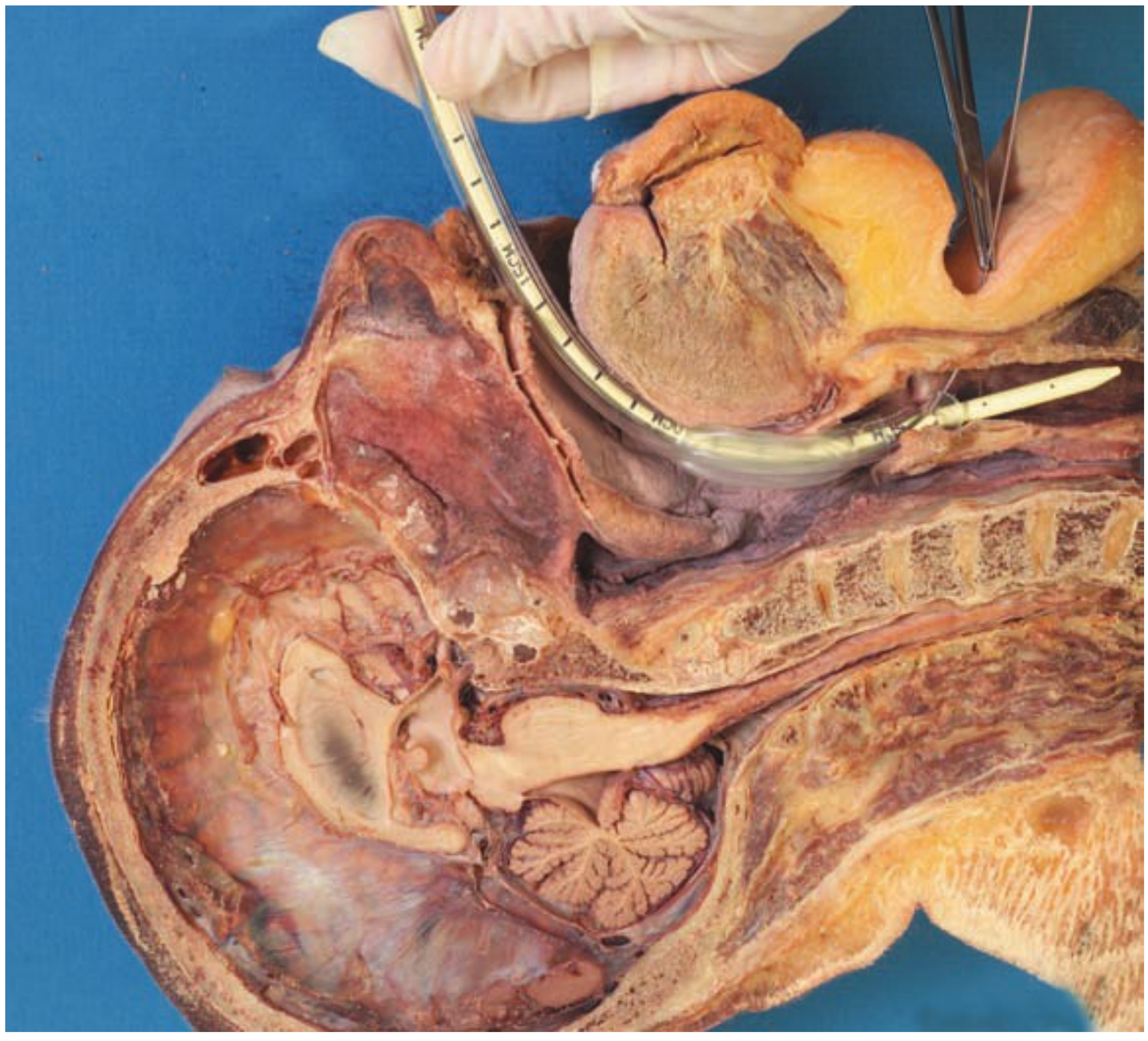


FIGURE 22-13 The guide catheter can be removed after the ETT is advanced to the CTM, and then advanced down the tube, alongside the wire, and into the trachea. This helps to ensure that the ETT, when further advanced after removal of the wire, slides further down into the trachea and is not dislodged.

Complications

- Sore throat or hoarseness
- Trauma to larynx from introduction of needle or wire
- Bleeding/hematoma/infection
- Inadvertent puncture of esophagus (or wire introduction)
- Wire may pass distally into trachea, rather than into mouth
- Oral or nasal trauma from wire or passage of ETT
- Folding of tracheal tube inside airway
- ETT may be inadvertently removed from larynx when wire and guide catheter are removed, resulting in misplaced tube

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PART VII

Fiberoptic Techniques

CHAPTER 23

Flexible Fiberoptic Bronchoscope Intubation

Katherin A. Peperzak and Manuel C. Vallejo

Concept

Fiberoptic bronchoscopes (FOBs) serve many purposes, both diagnostic and therapeutic. Relatively unchanged since their development by Shigeto Ikeda in 1966, FOBs are available in various sizes for different uses and are usually 55 or 60 cm in length.[1] Instruments used solely for intubation tend to be smaller in diameter (1.8 to 4.0 mm) than those used for diagnosis and therapy of pulmonary disease, which facilitate passage of biopsy forceps and other instruments through a larger working channel. The FOB consists of a light source, an insertion cord, and a handle. Generally, light is transmitted to the handle of the scope by fiberoptic bundles in a "universal cord" connected to an external medical-grade endoscopic light source. The light is then transmitted from the handle to the end of the scope by another set of fiberoptic bundles routed through the insertion cord. Also along the length of the insertion cord are control wires, which provide for flexion and extension of the tip of the scope; a hollow working channel that allows for suction, administration of local anesthetic or lavaging fluid, passage of instruments, or insufflation of oxygen; and an image transmission bundle, which is protected by a lens at its distal end. The handle of the FOB contains an eyepiece, a diopter adjustment ring, a control lever connected to the previously mentioned control wires, a suction button, and an access port to the working channel. Many FOBs have integrated cameras that allow for real-time video display on an external monitor. Alternatively, a camera may be attached to the eyepiece.

Intubation using a FOB may be performed on an awake or asleep patient, though in patients with an anticipated difficult airway it is generally accepted that maintaining consciousness and a protected airway until the airway is secured increases the safety of anesthesia.[2–4] Like an optical stylet, the FOB allows the user to move his or her vantage point into the airway, guiding the tip of the instrument to the trachea, then threading the endotracheal tube (ETT) over it into the airway. The technique allows for enhanced maneuverability around even the most difficult anatomy and immediate confirmation of ETT placement.[5] It can be performed on all age groups through a nasal or oral approach.

Providing adequate anesthesia to the airway is the key to intubating with the FOB in the awake patient. For the nasal approach, anesthesia can be applied topically by coating the nasopharyngeal airways with 2% to 4% lidocaine paste or gel (3 mL). To minimize risk of epistaxis this may be combined with topical vasoconstrictor solution, such as 0.5% phenylephrine or 0.05% oxymetazoline (1 mL). Cotton-tipped applicators can be soaked in local anesthetic solution and placed in the nares, to accomplish the same ends. The glottis should be anesthetized as well, to allow the ETT to be advanced out of the nasopharynx without causing patient discomfort or coughing. For either the nasal or oral approach, this should be accomplished with transtracheal injection of 2 to 3 mL of 2% lidocaine solution through the cricothyroid membrane, or by spraying the same solution through the suction channel of the FOB as the cords are visualized. In addition, topical anesthesia to the larynx and trachea may be accomplished with a nebulized solution of 2% lidocaine (2 to 5 mL).

For the oral approach, anesthesia in the oral cavity can be achieved with a combination of superior laryngeal nerve blocks and topical local anesthetic sprays, gargles, or paste (see chapter 8). Blocking the superior laryngeal nerve (branch of CN X), either transcutaneously above the thyroid cartilage or transmucosally with Krause forceps, provides anesthesia to the glottis above the vocal cords, as well as the laryngeal surface of the epiglottis. The lingual surface of the epiglottis, the oropharyngeal walls, and the posterior tongue can be anesthetized with local anesthetic sprays (such as benzocaine or nebulized lidocaine), pastes, or gels (usually 4% or 5% lidocaine). A transmucosal injection of 1 to 2 mL of 2% lidocaine at the base of the anterior tonsillar pillar blocks the lingual branch of the trigeminal nerve (CN V_3), anesthetizing the anterior two-thirds of the tongue. An injection of a similar dose of lidocaine in the gutter between the tongue and the gingivae, at the base of the palatoglossal arch, anesthetizes the lingual

branch of the glossopharyngeal nerve (CN IX), suppressing the gag reflex. With all of these methods of providing topical anesthesia, the cumulative dose of local anesthetic should be quantified, and toxic doses (eg, >5 mg/kg of lidocaine) must be avoided, as absorption from these vascular sites can occur rapidly.

Evidence

Numerous studies and case series attest to the utility of the FOB in the management of the routine and especially the difficult airway.[6–10] The American Society of Anesthesiologists difficult airway algorithm includes a section on awake intubation as well as pathways calling for "Alternative Approaches to Intubation," which includes use of fiberoptic scopes.[11] Although there is no advocated "best" device for use in these situations, use of the FOB is probably the oldest and best-described technique.[12] Surveys of anesthesiologists in the United States indicate that the FOB is the preferred intubation device in the management of the difficult airway.[13] Further, fiberoptic intubation is associated with greater hemodynamic stability and less morbidity compared with direct laryngoscopy.[14] In unanticipated difficult airways, intubation over the bronchoscope can be successfully performed through a laryngeal mask airway (LMA) and around the esophageal tracheal Combitube.[3,4,15]

The utility of FOB for intubation of patients with suspected or confirmed cervical spine injuries where movement can further damage (transect) the spinal cord is well established. It can be performed without any movement of the cervical vertebrae and allows for evaluation of neurologic function in awake patients throughout and after the procedure.[4,7,9] Intraoperatively, the FOB has proven to be useful during a case of accidental tracheal extubation in a patient in the prone position with her neck flexed and pinned in a Mayfield head holder for craniotomy. Use of an LMA or mask ventilation was limited due to the patient's extreme positioning, but the airway was successfully rescued via fiberoptic intubation.[16]

The FOB is also beneficial for patients with known trauma to the airway because it allows placement of the ETT beyond the level of the injury and therefore reduces the risk of creating a false passage.[4] Furthermore, the FOB is particularly useful in cases of lingual tonsillar hyperplasia, a common cause of airway obstruction and difficult intubation. Ideally, these patients should undergo awake intubation, but in cases of unanticipated lingual tonsillar hyperplasia, a technique successfully using the FOB through the bronchial lumen of a double-lumen ETT and a rigid stylet through the tracheal lumen has been described.[17] In patients with particularly distorted anatomy or severe airway obstruction, other potentially useful adaptations to fiberoptic intubation include the use of guidewires through the working channel of the FOB and "fibercapnic intubation," which uses CO_2 measurements to confirm placement.[18] The simultaneous use of direct laryngoscopy with FOB may improve the success rate of the technique by displacing soft tissues that can impede the fiberscopic view of the glottis.[19]

It is important to note that even during a straightforward awake intubation, the operator performing the procedure may meet resistance while advancing the ETT over the FOB, thus failing tracheal intubation on the first attempt. Video data from a study by Johnson et al[20] reveal the ETT tube to be most commonly obstructed by the right arytenoid (42% of all patients undergoing awake intubation) or the interarytenoid soft tissues (11%). Rotating the ETT 90° counterclockwise such that the bevel faces posteriorly often results in successful passage of the tube on subsequent attempts. The authors suggest orienting the ETT in this position, and positioning the FOB in the center of the arytenoids on the initial attempt may increase the success rate and therefore reduce potential laryngeal injury.

Ultra-thin fiberscopes with outer diameters as small as 2.5 mm are available for the pediatric and neonate population.[1,21] Fiberoptic intubation has been successfully applied in various pediatric difficult airway situations, such as congenital anomalies including microagnathia,[22] trauma,[23] and airway obstruction due to edema.[24] Although a multitude of difficult fiberoptic-compatible oral airways is available for adults,[1,25] the LMA is the most commonly used device to facilitate introduction of the bronchoscope in pediatrics and may be used with or without an airway exchange catheter and/or guidewire.[21] As is readily evident, there are many advantages to the FOB technique, including applicability to all age groups, excellent airway visualization, ability to insufflate oxygen during the procedure, high success rate, and immediate confirmation of ETT placement.[9]

Preparation (Figs. 23-1–23-9)

- Set up for direct laryngoscopy (see Chapter 5)
- Inject antisialagogue (0.2 to 0.4 mg glycopyrrolate) 15 to 20 minutes prior to anticipated procedure
- For awake procedure, topicalize or block nerves of pharynx and oral cavity (or nasal cavity, if it is to be a nasotracheal procedure)
- If nasotracheal approach is planned, coat nasopharyngeal airway with topical vasoconstrictor solution, such as 0.5% phenylephrine or 0.05% oxymetazoline
- For awake procedure, topicalize larynx with nebulized lidocaine, lidocaine spray from scope tip, or transtracheal injection of 2% lidocaine (2 to 3 mL)

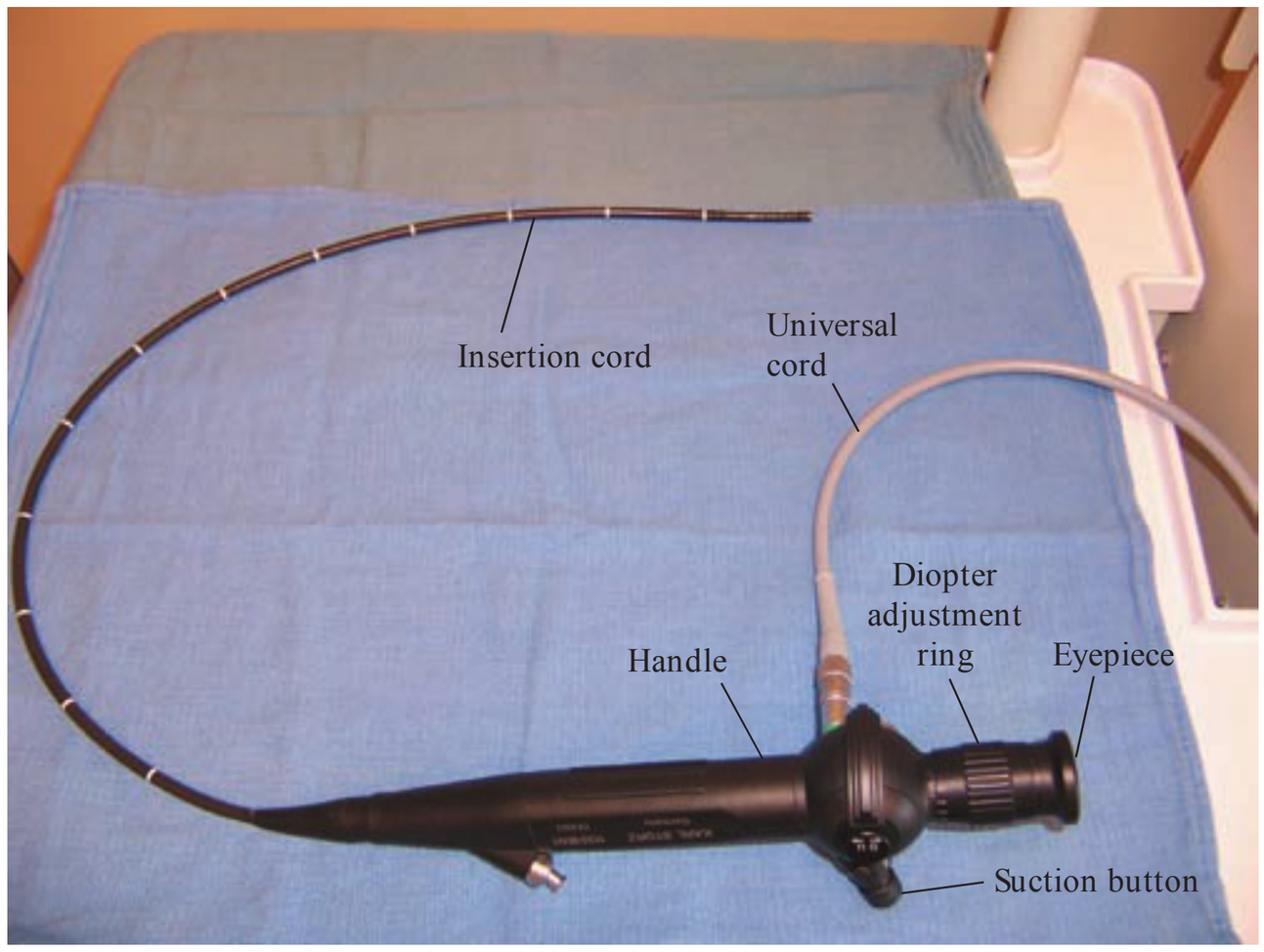


FIGURE 23-1 Typical fiberoptic intubating scope: note insertion cord, universal cord, and handle.



FIGURE 23-2 Equipment for oral fiberoptic awake intubation.



FIGURE 23-3 Equipment for nasal fiberoptic awake intubation.



FIGURE 23-4 Commercially available atomizers allow a fine spray to be directed to the pharynx or back of the tongue.



FIGURE 23-5 Transmucosal injection of local anesthetic in the "gutter" between the posteriormost molar and the tongue provides anesthesia to lingual branches of the glossopharyngeal nerve (CN IX). Needle insertion should be limited to 0.5 to 1 cm of depth, with careful aspiration to avoid intravascular injection.



FIGURE 23-6 Transmucosal approach for superior laryngeal nerve block (CN X). Krause forceps with a lidocaine-soaked pleget are placed in pyriform recesses on each side.



FIGURE 23-7 Transcutaneous approach for superior laryngeal nerve block (CN X). A 22G to 25G needle is inserted just medial and cephalad to the greater horn of the thyroid cartilage on each side.



FIGURE 23-8 Lidocaine nebulization for laryngeal and tracheal anesthesia.



FIGURE 23-9 Anesthestizing the glottis by transtracheal lidocaine injection through the cricothyroid membrane. If desired, a 20G intravenous catheter can be used for this purpose to prevent injury to the airway by a needle in the event the patient coughs during injection. Anesthesia may also be achieved by administering lidocaine through the suction channel of the FOB as the cords are visualized.

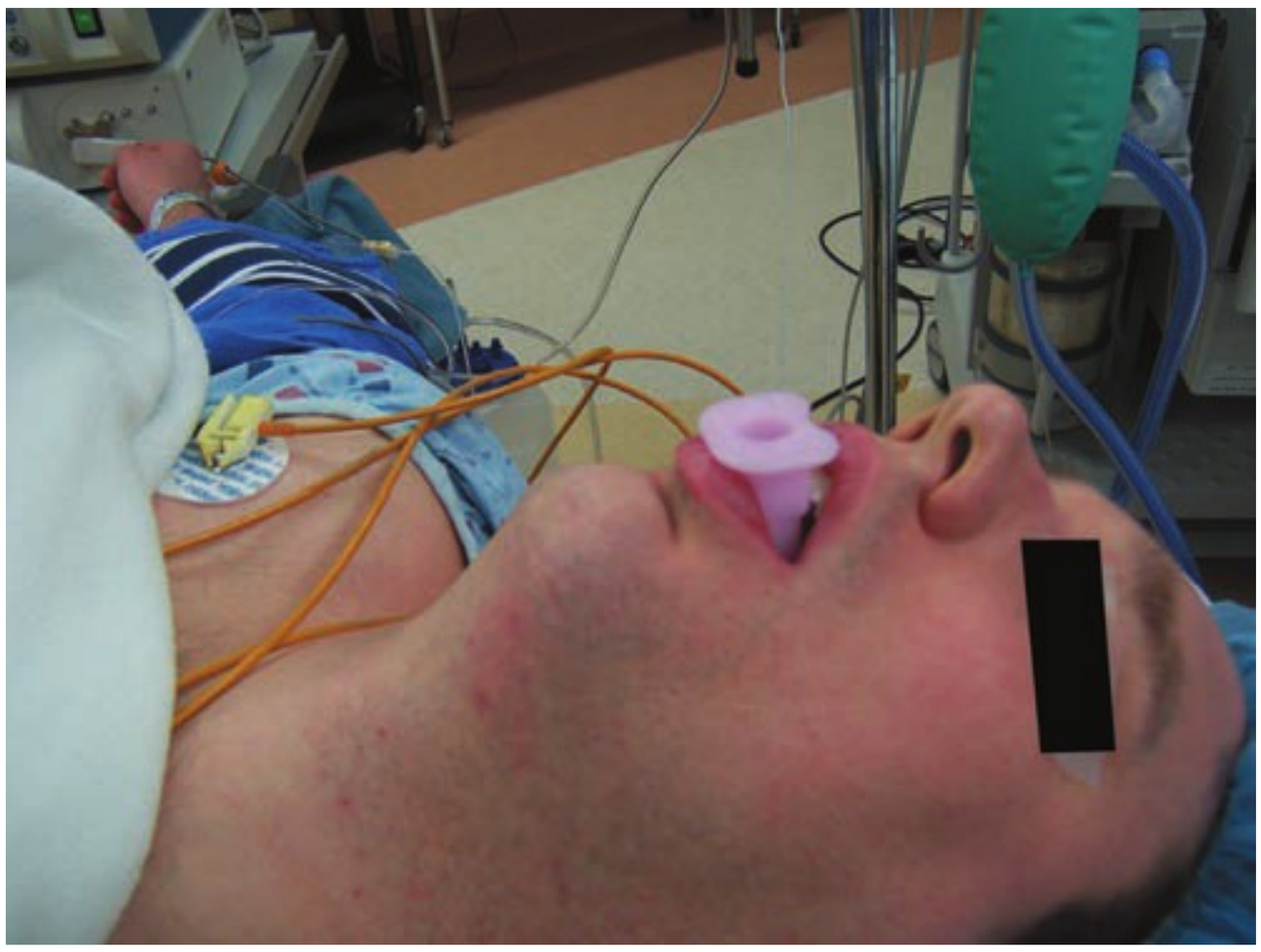


FIGURE 23-10 Williams airway inserted for FOB intubation in anesthetized patient.

- Lubricate FOB
- Load ETT on FOB
- Administer mild sedation but preserve cooperation and airway reflexes
- Patient may be supine or, if intubation is to be carried out awake, may also be seated or semirecumbent
- Check light source and image, focus if necessary
- Coat end of scope with antifogging solution
- Preoxygenate patient
- Stand at the head of the patient (it is also possible to stand in front of the semirecumbent patient, if awake intubation is performed)

Procedure (for Orotracheal FOB Intubation) (Figs. 23-10–23-20)

- Place oral Williams, Bermann, or Ovassapian airway, or have assistant use laryngoscope to elevate and compress tongue; a simple jaw thrust may also suffice
- A mask with diaphragm (such as a Patil-Syracuse mask), or anesthesia circuit with adaptor for FOB can be used with oral airway to maintain ventilation during FOB
- Pass FOB through oral airway, mask, or bronchoscopy adaptor
- Maintain scope tip in midline
- Guide scope forward, curving the tip toward the glottis: upward and downward pressure applied with the thumb on the tip control lever curves the tip
- Turn handle and scope tip as a unit; avoid twisting the insertion cord, which can break fibers
- Visualize glottis through scope
- Spray vocal cords with 1% lidocaine (2 mL) unless already topicalized with transtracheal injection or nebulization
- Identify cords, advance scope between them
- Advance scope tip until carina is in sight
- Stabilize FOB and advance ETT (or have the assistant do this)
- If resistance occurs, ETT bevel may be hung up on arytenoid cartilage or aryepiglottic fold: withdraw ETT slightly and turn 90° counterclockwise, then attempt to advance gently
- After tube passes into airway, remove FOB while visualizing tracheal rings and ETT in airway on withdrawal
- Confirm placement of ETT with detection of CO_2 and auscultation after scope is removed

Practicality

- Unfamiliar and complex: requires considerable practice
- Very expensive: scope, cart, and light source run to more than $5,000
- Awkward, multiple components, not easily portable
- Battery-operated FOB reduces complexity and improves portability
- Time-consuming: with patient preparation, awake FOB intubation may require more than 20 minutes
- Requires logistic support for cleaning, maintenance
- Most FOBs have a finite number of uses due to routine wear and tear requiring expensive maintenance, repairs, or replacement

Indications

- Predicted difficult intubation
- Immobile cervical spine (halo, collar, in-line immobilization)
- Difficult laryngoscopy with preserved mask ventilation



FIGURE 23-11 Insertion of FOB for oral intubation, from top of patient.



FIGURE 23-12 Insertion of FOB for oral intubation, from front of an awake, semirecumbent patient.



FIGURE 23-13 Jaw thrust during oral FOB insertion permits visualization of the glottis.



FIGURE 23-14 Oral ETT insertion over FOB.

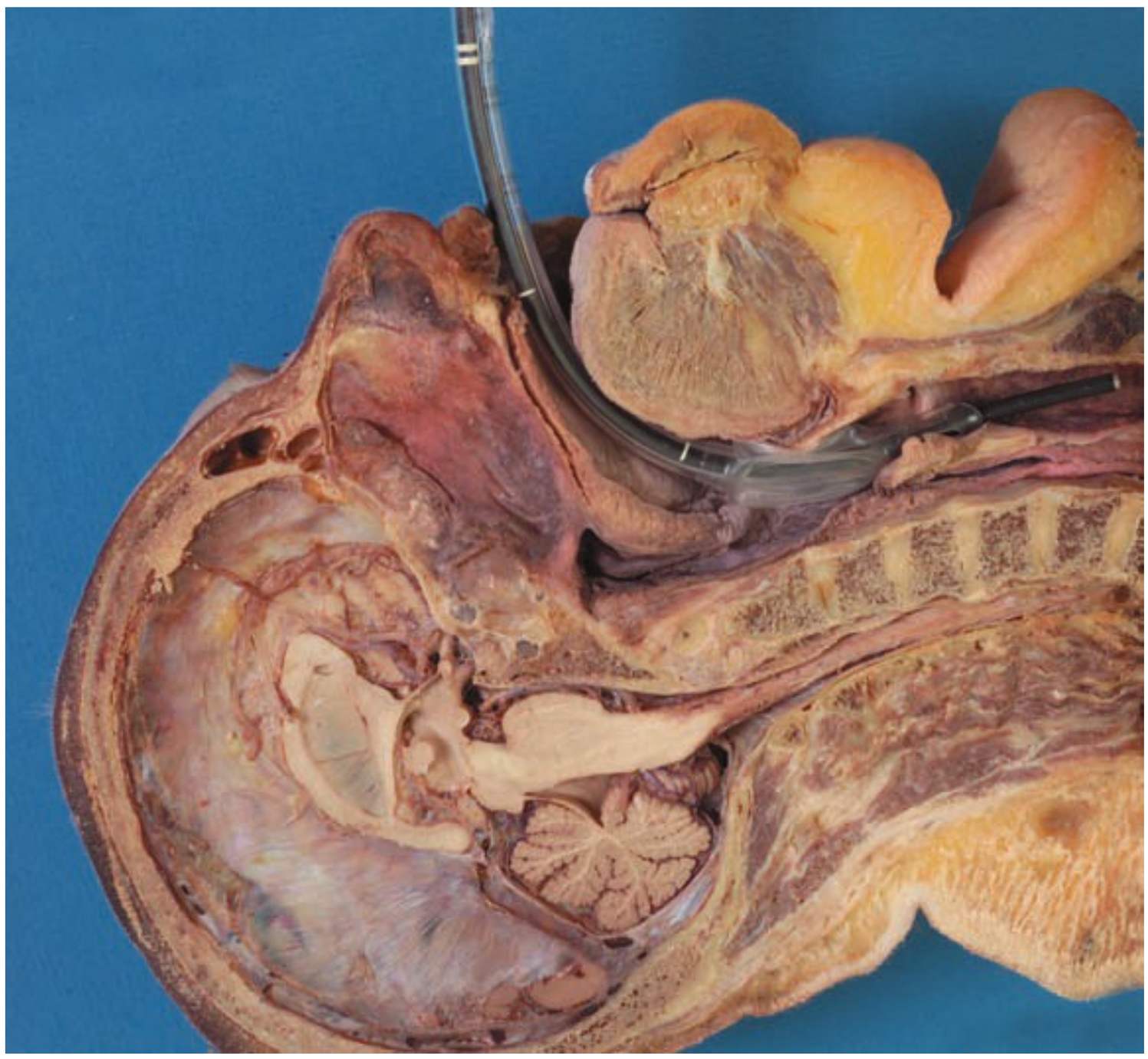


FIGURE 23-15 Oral FOB approach: insertion of ETT and FOB in cadaver specimen.

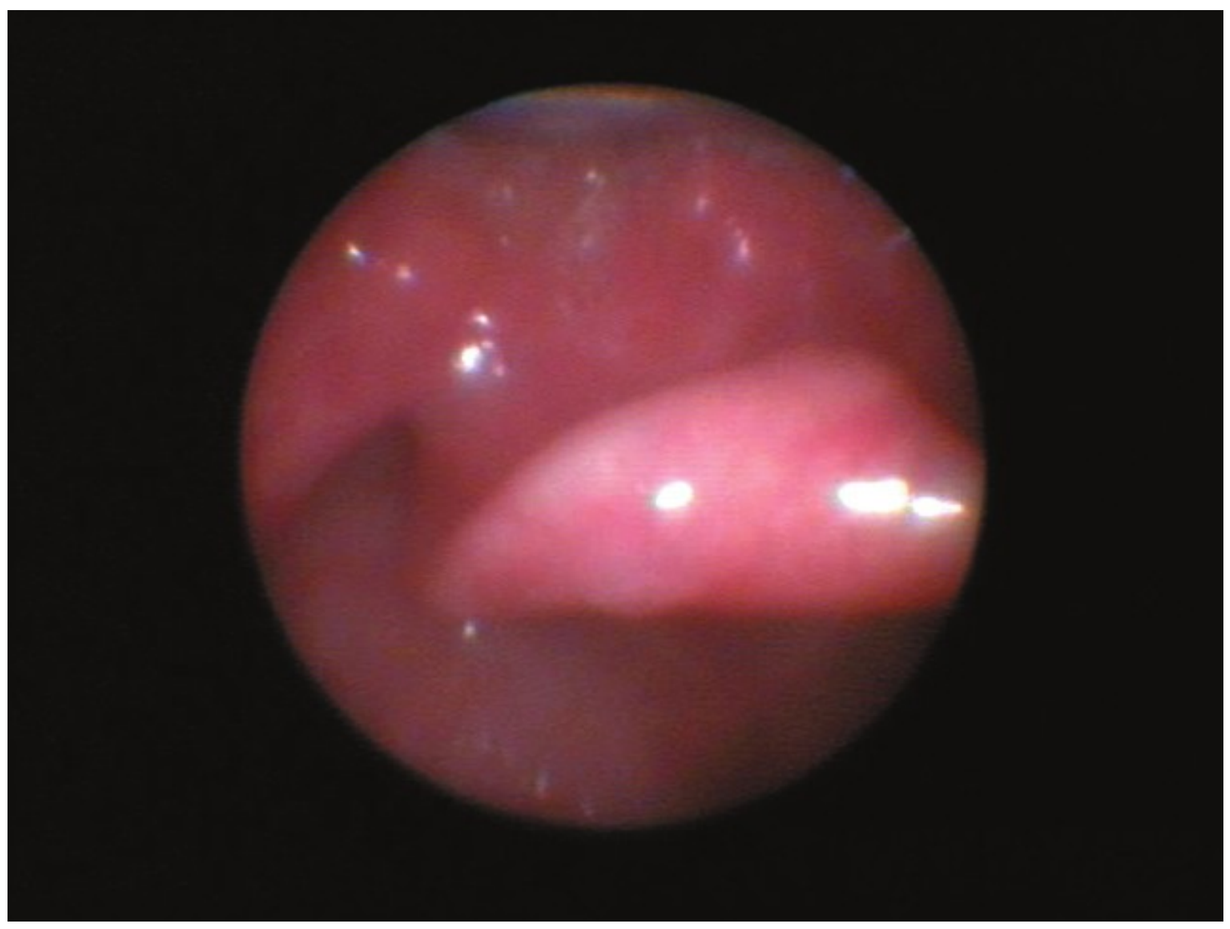


FIGURE 23-16 Epiglottis as seen through FOB during oral approach.

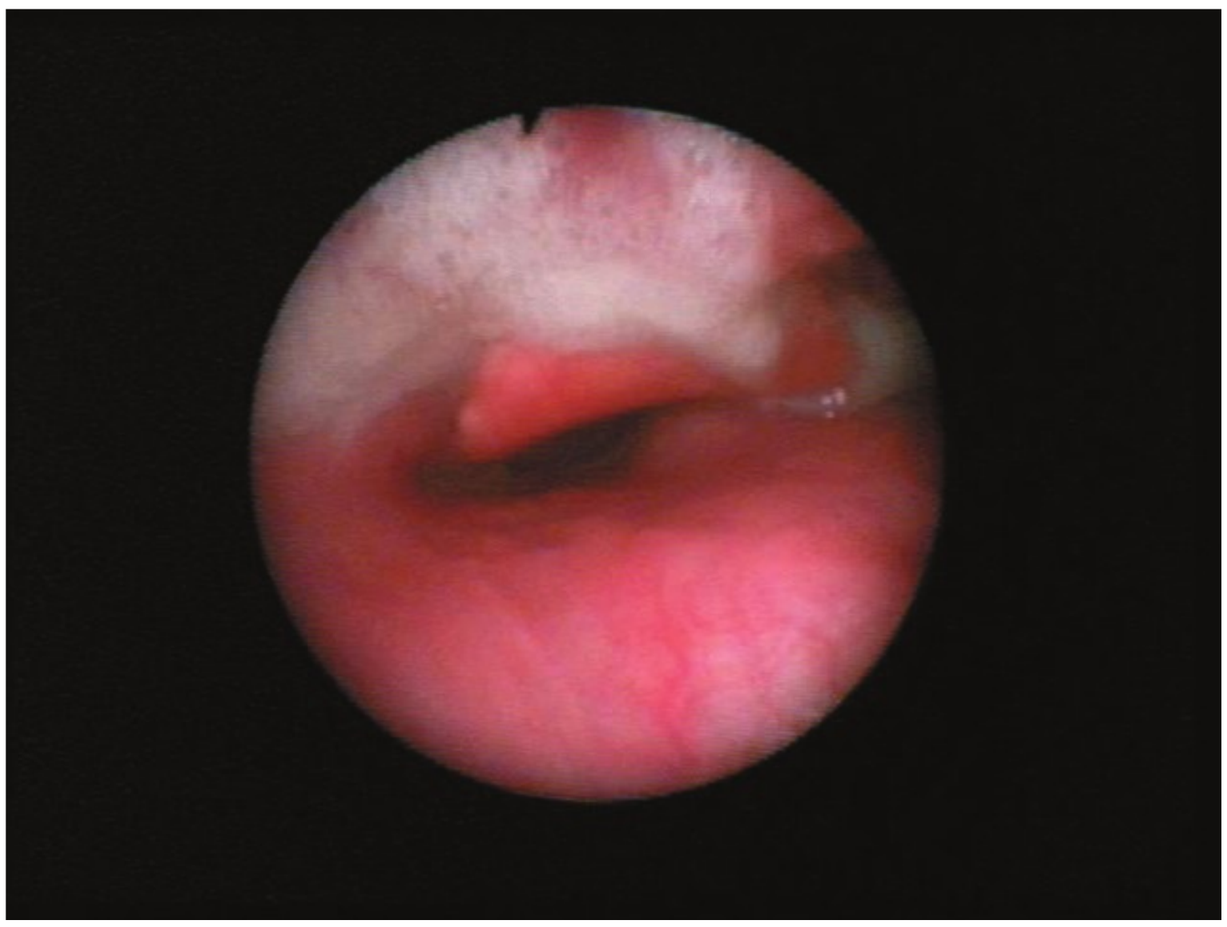


FIGURE 23-17 Poor view of glottis as seen through FOB during oral approach: epiglottis seen lying against posterior pharyngeal wall, obscuring view of glottis (jaw thrust dramatically improved the view, as seen in Figure 23-18).



FIGURE 23-18 Improved view of glottis, as seen through FOB after jaw thrust.



FIGURE 23-19 After entering larynx, tracheal rings are apparent, as seen through FOB.

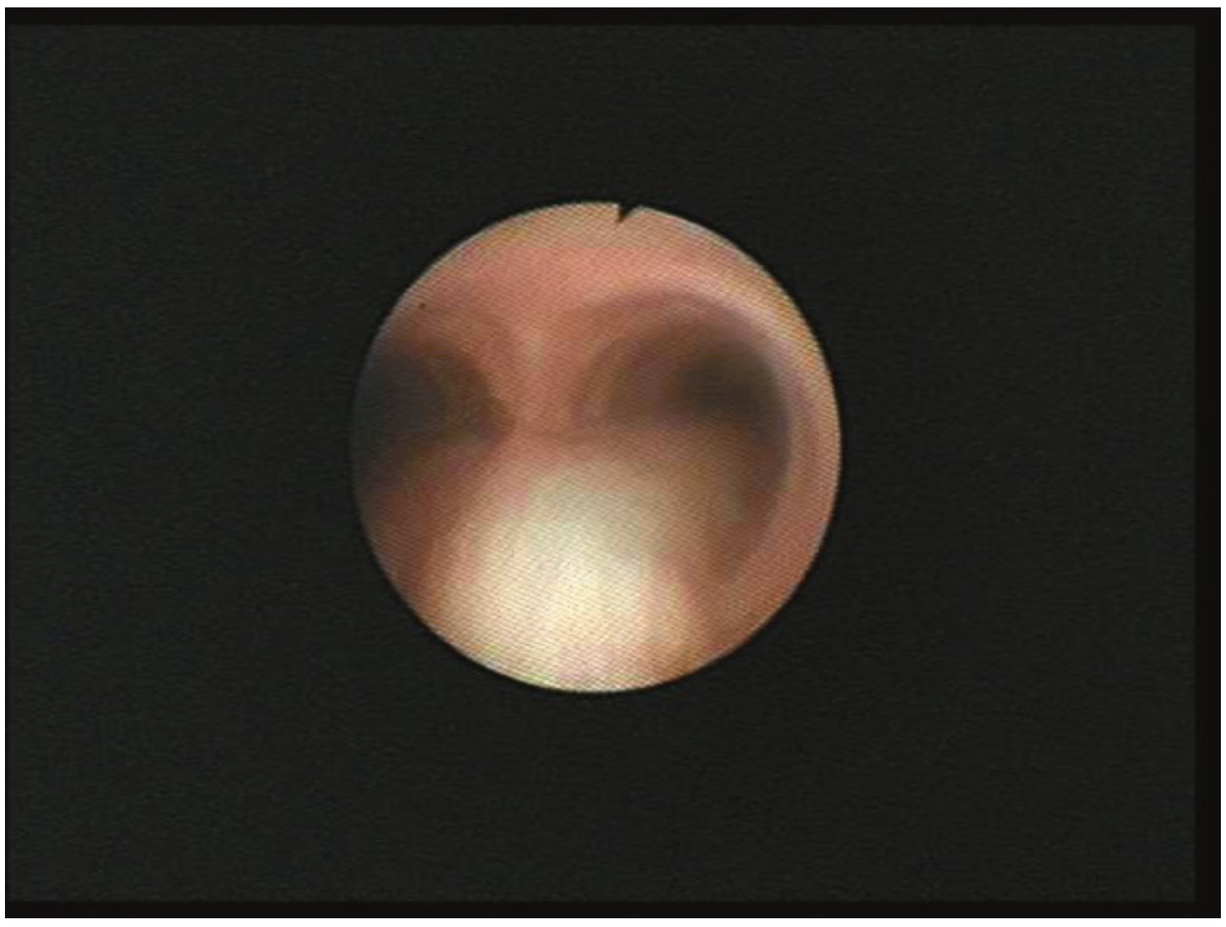


FIGURE 23-20 Carina, as seen through FOB.

Contraindications

- Emergent intubation (due to time requirements)
- Uncooperative patient (will not permit awake procedure)
- Copious blood and secretions in airway
- Inaccessibility of oral cavity

Procedure (for Nasal FOB Intubation) (Figs. 23-21–23-24)

- Insert FOB into anesthetized, prepared nare
- Advance along floor of nose
- Visualize nasopharynx, curve tip of scope down toward glottis
- Larynx should be in view
- Advance tip of scope to glottis
- Spray cords with 1% lidocaine ([2 mL], unless already topicalized)
- Advance tip of scope through glottic opening, confirm by noting tracheal rings
- Continue to advance tip of scope until carina is visualized
- Stabilize scope and advance ETT over scope into nose
- Proceed with ETT insertion, through glottic opening
- Alternatively, place ETT through nose to level of nasopharynx, then insert FOB, advancing into airway, followed by introduction of ETT
- If ETT "hangs up" at larynx (Fig. 23-25), avoid force, and pull back ETT slightly, rotating it counterclockwise 90°, then readvance gently
- Confirm ETT is in airway as scope is withdrawn
- Reconfirm ETT position with usual means



FIGURE 23-21 Nasal approach for FOB intubation, in awake, seated patient.



FIGURE 23-22 Insertion of FOB through nasal cavity in cadaver specimen.

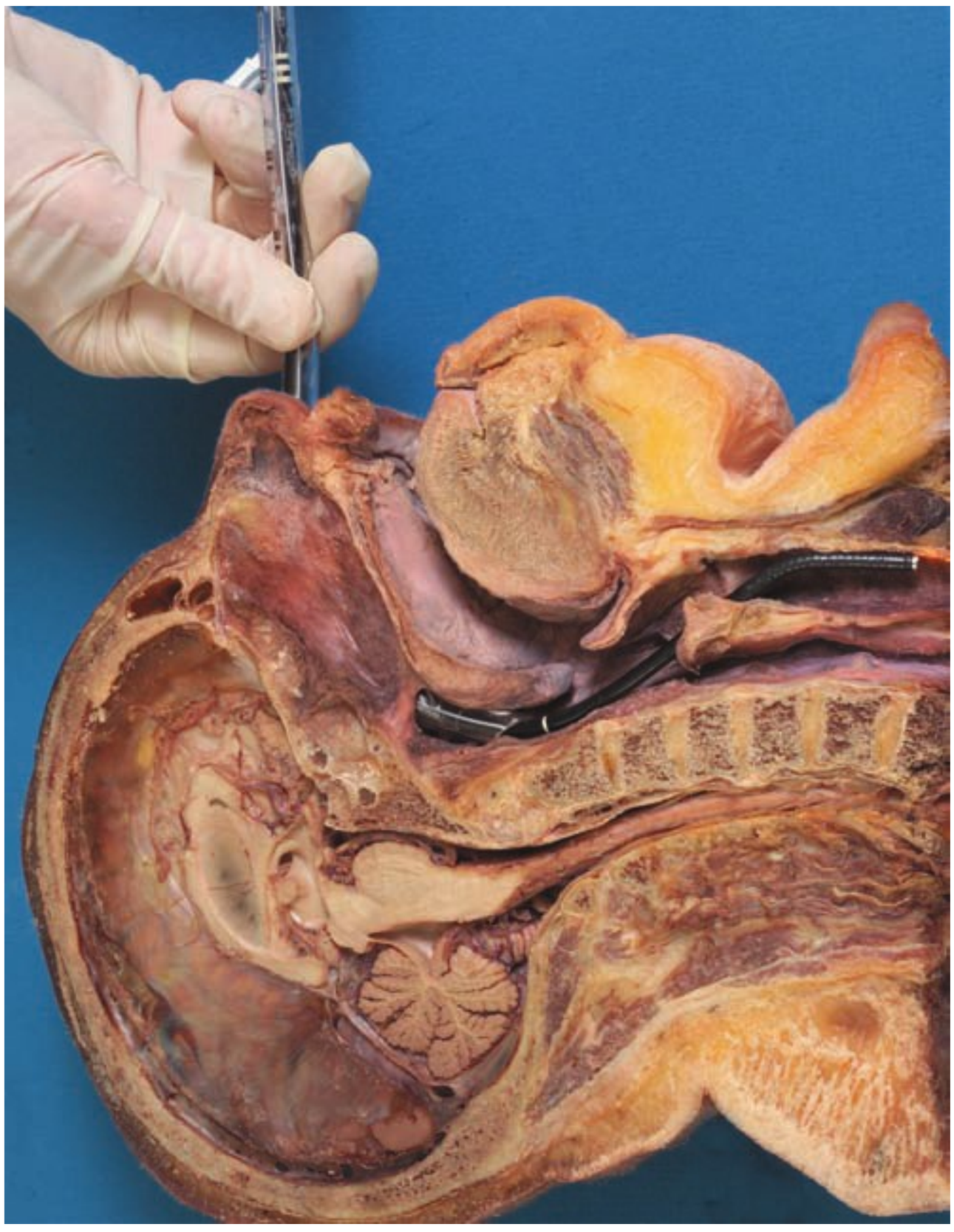


FIGURE 23-23 ETT advancement into nasopharynx over FOB.

Indications

- Inaccessibility of oral cavity
- Cervical spine injury or immobility
- Predicted difficult intubation

Contraindications

- Emergent intubation (due to time required)
- Coagulopathy or anticoagulation (due to risk of epistaxis)
- Uncooperative patient
- Copious blood or secretions in airway
- Head or facial tumor

Complications of Oral and Nasal FOB Intubation

- Inability to visualize airway (due to secretions, fogging, or tip of scope deviating laterally)
- Misplacement of ETT
- Trauma to larynx from insertion of ETT over the scope
- Patient intolerance of awake procedure, usually due to insufficient topicalization of mucosa
- Inability to pass ETT (occurs in up to 10% of cases), requiring smaller ETT to be used
- Mainstem bronchus intubation
- Patient hypoxia due to prolonged attempts, or failure to ventilate during attempts at intubation
- Epistaxis (from nasal approach)

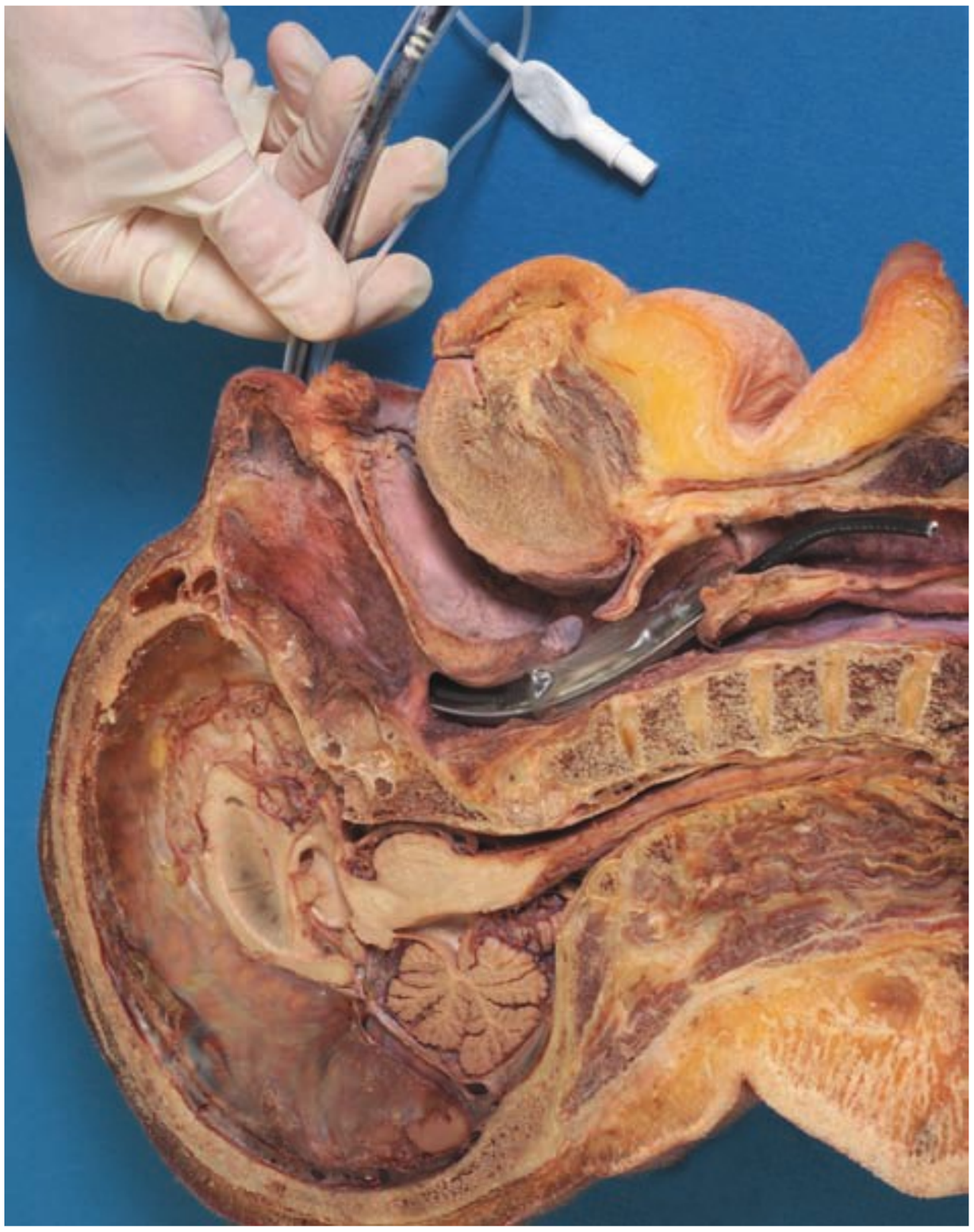


FIGURE 23-24 ETT placed over FOB into larynx.

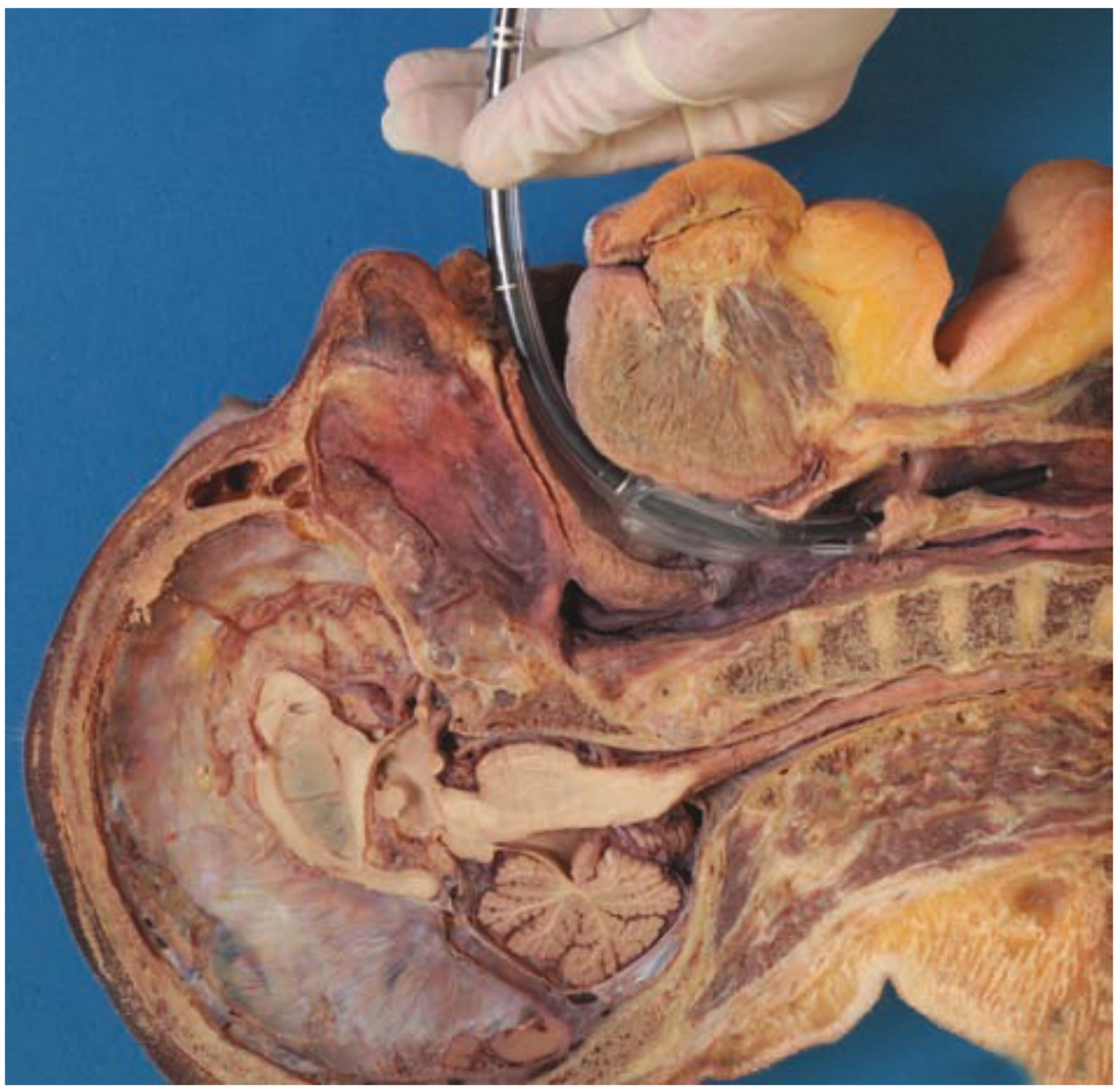


FIGURE 23-25 Bevel of ETT "caught" on aryepiglottic fold during tube insertion, preventing intubation of trachea. Pulling the ETT back a few centimeters, rotating it 90° counterclockwise, and readvancing usually solves this problem.

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CHAPTER 24

Rigid Fiberoptic Scopes and Video Laryngoscopes

Joshua S. Baisden and Michael Mangione

Concept

Similar to their flexible counterparts, rigid fiberoptic scopes are devices that permit indirect observation of the glottis and allow the operator to visualize passage of the endotracheal tube (ETT) into the airway. Newer devices, called videolaryngosopes, resemble conventional laryngoscopes but allow visualization of the airway on a video screen mounted nearby or attached to the handle of the device. Currently, the most commonly used of these devices is the GlideScope videolaryngoscope or GVL (Verathon Inc., Bothell, WA, USA; Figs. 24-1 and 24-2). Other promising videolaryngoscopes are the Pentax AWS (Hoya Corp., Tokyo, Japan; Figs. 24-3 and 24-4) and the C-MAC Storz (Karl Storz, Tuttlingen, Germany; Fig. 24-5). Older, but well-described devices include the Bullard laryngoscope (Gyrus ACMI, Southborough, MA, USA; Fig. 24-6), the Upsherscope (Mercury Medical, Clearwater, FL, USA; Fig. 24-7), and the WuScope (Achi Corp. San Jose, CA, USA; Fig. 24-8). Rigid fiberoptic scopes are inserted into the hypopharynx to obtain a view of the glottis rather than into the airway like flexible fiberoptic scopes. The ETT is then inserted into the airway while visualizing its progress with the scope. Some types have a stylet onto which the ETT is loaded, whereas others require freehand insertion.

Rigid fiberoptic scopes may be used routinely in airway management, but they have proven to be very useful in placement of the ETT when there is difficulty in aligning the oral, pharyngeal, and laryngeal axes, such as in patients with cervical spine immobilization or atlanto-occipital joint disease.[1,2] Rigid videolaryngoscopes have also proven to be invaluable as a teaching tool. These devices allow the apprentice to visualize airway anatomy such as the epiglottis and glottis by looking at the video screen. The teacher is able to look at the video screen and help to guide the process of intubation using real-time visualization.

The GVL is a commonly used and well-studied rigid scope. This device features a blade similar to a Macintosh blade, but the GVL blade is made of durable plastic and has a more acute distal curvature (60°). There is an accompanying video camera at the distal end of the blade that serves to project an image of the glottis on a liquid crystal display (LCD) monitor.[3] Insertion of the GVL classically follows a midline approach. After visualization of the uvula, the GVL blade is inserted in the vallecula or alternatively passed beyond the epiglottis if the epiglottis obstructs viewing the glottis.[3] With the glottis in view on the monitor, the ETT is then passed into the airway with visual confirmation of ETT placement. Achieving an adequate view of the glottis with the GVL appears routine, although placement of the ETT can remain difficult due to the curvature of the GVL blade; thus, use of a rigid sylet is recommended during ETT placement.[3,4]

One of the newest additions to the rigid fiberoptic scope collection is the Pentax AWS. This innovative device consists of a 2.4″ LCD full color monitor, a 12-cm cable with a charge-coupled device camera, and a disposable clear blade (PBlade, Hoya Corp., Tokyo, Japan). The disposable PBlade is placed over the image cable leaving the camera approximately 3 cm from the tip of the blade. The PBlade allows an ETT to be attached to the right side of the blade to facilitate ETT placement (compatible with ETT sized 6.5 to 8.0). The PBlade also houses a port through which a suction catheter can be passed. The entire device is powered by two AA alkaline batteries that allows continuous operation for up to 1 hour. Insertion of the Pentax AWS is similar to the insertion of a Miller blade, with the distal end of the blade placed on the glottic side of the epiglottis. There is a sighting device on the LCD monitor that allows the user to align the tip of the ETT with the glottic opening to assist with ease of intubation.[5,6]

The original model for the rigid fiberoptic scope is the Bullard laryngoscope. This device features a blade contour designed to match the anatomy of the upper airway. The blade then mounts onto a standard laryngoscope handle. The Bullard laryngoscope encompasses a fiberoptic bundle that lies on the posterior aspect of the blade and is located near the end of the blade. It also possesses a working channel that runs the entire length of the blade for introduction of medications, suction, or oxygen insufflation. Intubation with the Bullard is achieved by the operator inserting the scope in a midline pathway into the hypopharynx in an anesthetized patient. The operator then advances the blade into position cephalad to the glottis. This yields an excellent view of the larynx. The ETT can then be pushed forward off the stylet (or placed freehand), into the glottis, while observing placement through the instrument.



FIGURE 24-1 The GVL featuring Mac 3, Mac 4, Mac 5 blades and rigid stylette.
(Courtesy of Verathon Inc., Bothell, WA, USA.)

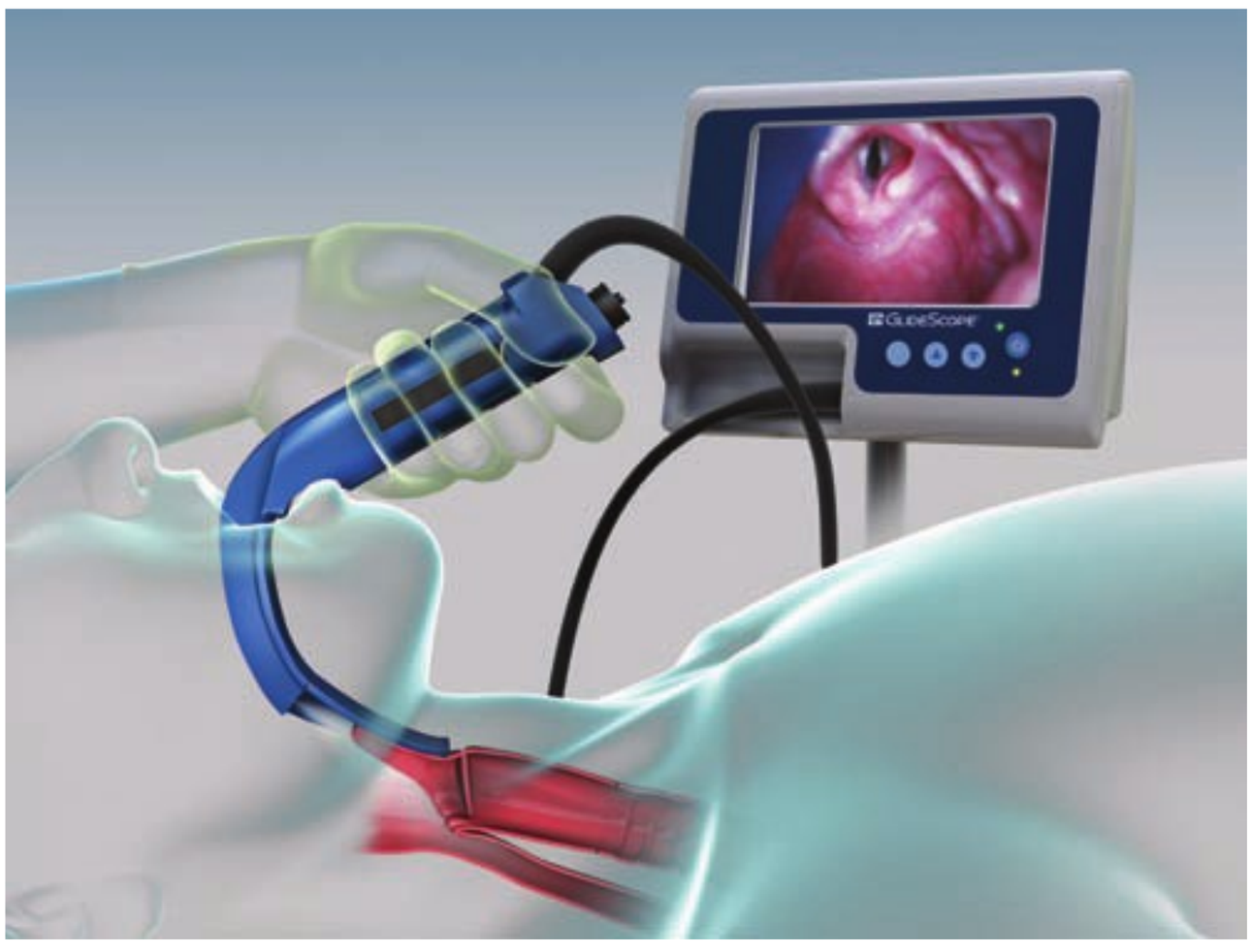


FIGURE 24-2 View of glottis with the GVL.
(Courtesy of Verathon Inc., Bothell, WA, USA.)



FIGURE 24-3 Pentax AWS with ETT.
(Courtesy of Ambu Corp., Ølstykke, Denmark.)



FIGURE 24-4 Pentax AWS and disposable clear blade.
(Courtesy of Ambu Corp., Ølstykke, Denmark.)



FIGURE 24-5 The Storz C-MAC and conventional MAC blade.

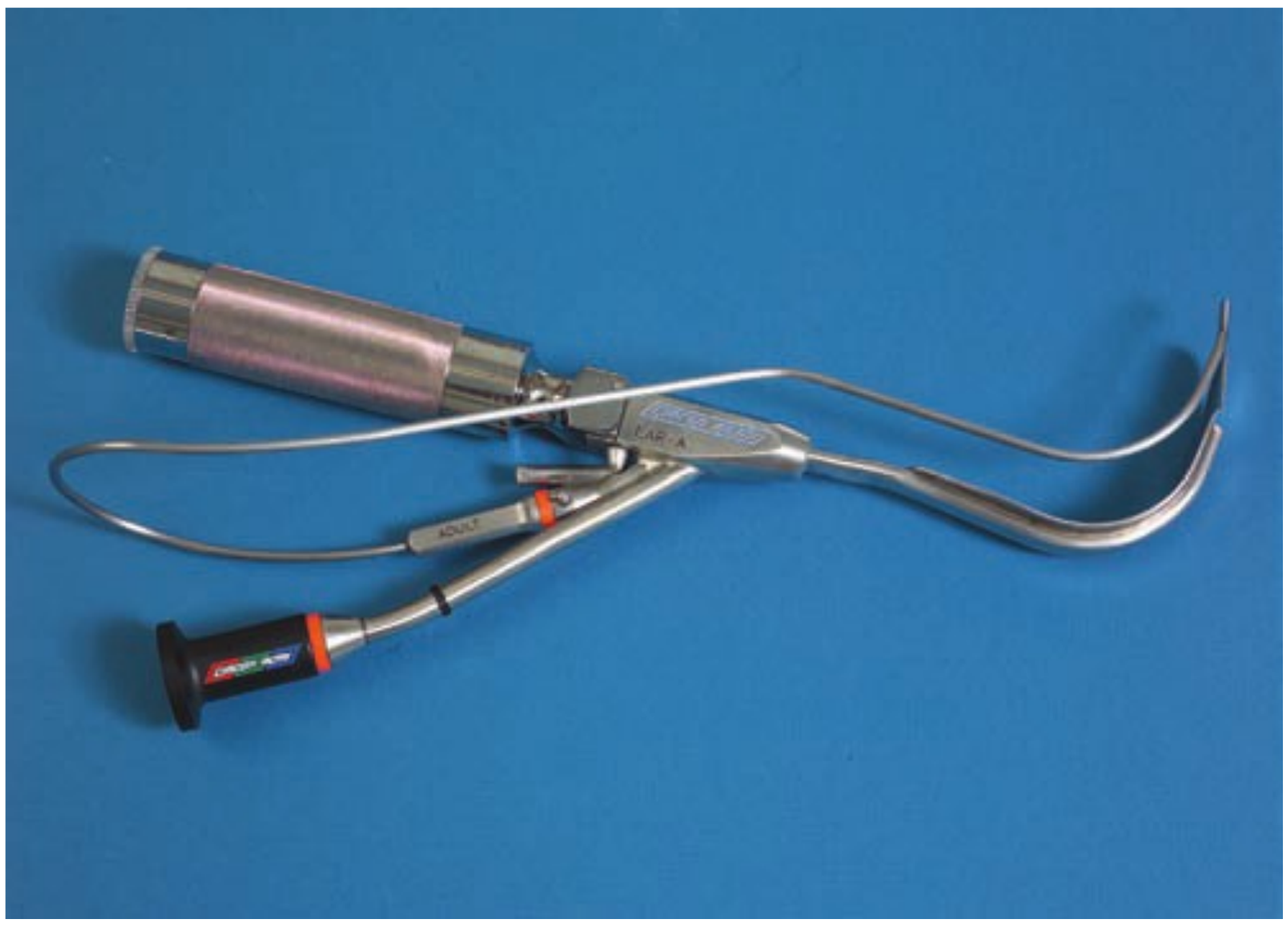


FIGURE 24-6 The Bullard laryngoscope.



FIGURE 24-7 The Upsherscope.
(Courtesy of Mercury Medical, Clearwater, FL, USA.)



FIGURE 24-8 The WuScope.
(Courtesy of Achi Medical Products, San Jose, CA, USA.)

Evidence

The GlideScope has been extensively evaluated since its introduction to clinical practice in late 2001. Numerous studies have compared the laryngeal view obtained by the GVL and direct laryngoscopy (DL). In their 2005 study, Cooper et al[3] show that the GVL was able to produce a Cormack-Lehane (C/L) grade 1 or 2 view in 99% of patients enrolled in the study. The same study also shows that in 133 patients who underwent both GVL and DL, the C/L grade 1 views were 85.7% versus 48.9%, respectively.[3] Several other studies support an improved C/L grade when comparing the GVL with the conventional DL.[7–9] The GVL has also been shown to improve the rate of successful tracheal intubation when compared with the DL.[8,10,11] Malik's[8] 2009 study shows a 96% intubation success rate with the GVL compared with the 84% success of DL. Inexperienced operators may benefit more from using the GVL compared with conventional DL.[10] Another commonly studied variable is time to intubation in the GVL compared with DL. Review of current literature does not give a consistent answer as to the efficiency of the GVL when compared with DL.

The Pentax AWS and C-MAC Storz have been extensively studied recently. Numerous studies support an improved C/L grade with the Pentax AWS compared with DL.[5,8,12,13] A recent study by Asai and colleagues[5] shows a 99.3% tracheal intubation success rate with the Pentax AWS in patients where DL with a Macintosh laryngoscope was difficult or failed. This device also appears to improve the C/L grade and success rate of tracheal intubation compared with DL in patients with restricted neck movement.[12,13] More studies need to be performed to see if there is a significant decrease in time to intubation using the Pentax AWS compared with conventional DL. The V-MAC Storz DCI has also been shown to improve the C/L grade when compared with conventional DL.[9] Maassen and colleagues[9] were able to show that use of the V-MAC Storz DCI required fewer attempts to secure the airway and decreased time to intubation when compared with the GlideScope and McGrath videolaryngoscope.

The Bullard has also been extensively evaluated. This device appears to be safe and effective for airway management in the patient with a potential cervical spine injury.[14] Watts[15] compared the time required for intubation and the degree of cervical extension using the Bullard scope versus that for DL, both with and without in-line cervical immobilization, in patients under general anesthesia. The degree of spine extension and the time to intubate were similar, except when cervical immobilization was imposed, at which time the average duration required for intubation with the Bullard scope was significantly prolonged, ranging from 25 to 40 seconds.[15] However, Schulman[16] reported in a randomized trial in 50 patients under anesthesia that, in comparing the Bullard scope to a flexible fiberscope during in-line cervical immobilization, intubation was significantly easier to accomplish and required less time with the rigid apparatus. The Bullard scope has proven useful for management of normal and difficult pediatric airways.[17]

The Upsherscope, a rigid scope incorporating a C-shaped steel blade with the enclosed fiberoptic bundles and an intubation channel, proved to have no advantage over DL in enabling intubation in a group of 300 patients randomly assigned to airway management in the operating room by either technique.[18] In fact, the authors reported a 15% failure rate with the Upsherscope, compared with 3% with DL.[18]

New literature regarding the clinical utility of the GlideScope and other videolaryngoscope devices has continued to emerge. A recent study from Aziz et al[19] provided a retrospective chart review of all intubations occurring at two academic institutions over a 2-year period, 2,004 of which were GVL intubations. The researchers found an overall GVL success rate of 97% in all situations.[19] They also reported a 96% success rate (1,377 of 1,428) in patients with predictors of difficult DL.[19] Possibly, the most important statistic from this article was a 94% success rate (224 of 239) of GVL intubation following failed DL.[19] Predictors of failure with the GVL were masses in the neck, or prior surgery or radiation in this region. Currently, the GlideScope and other rigid videolaryngoscopes are not found in the American Society of Anesthesiologists difficult airway algorithm, though this study and others that attest to the utility of these devices raise the question of whether or not they should be included in future versions of difficult airway management recommendations.

Preparation for Use of the GVL (Fig. 24-1):

- Prepare for DL (refer to chapter 5)
- Select the appropriate size of GVL Blade (Fig. 24-1)
- Direct the tip of the blade toward a recognizable target and ensure appropriate image clarity and orientation on screen
- Place the pre-formed GVL stylet through the ETT

Procedure for Use of the GVL (Fig. 24-2):

- Place the GVL blade in the midline of the patients mouth
- Advance the blade tip into the hypopharynx while watching the screen
- Obtain an optimal image of the glottis (Fig. 24-2)
- Place the ETT through the glottic opening under direct visualization using the GVL screen

Remove the blade and confirm ETT position in the airway

Table 24-1

Rigid Fiberoptic Scope Overview

	Cost	Portability	Channeling	Disposable	Complexity
GlideScope	$10,000	No	No	No	Easy to learn to use
Pentax AWS	$9,000	Yes	Yes	Blade	Some learning curve
C-MAC Storz	$15,000–$20,000	Yes	No	No	Similar to DL
Bullard	$2,000–$3,000	No	Yes	No	Steep learning curve

RIGID FIBEROPTIC SCOPE GENERALIZATIONS

Practicality

- Improved success rate for tracheal intubation compared with DL, especially in patients limited neck range of motion or presumed difficult airway; improved C/L grade compared with DL

Complexity

- Less so than fiberoptic bronchoscope and similar to conventional DL

Affordibility

- Relatively expensive with devices ranging from $2,000 to $20,000 (Table 24-1)

Indications

- Predicted difficult intubation
- Patient with potential cervical spine injury requiring airway management
- Poor laryngoscope grade during DL

Contraindications

- Copious blood or secretions in airway
- Inaccessibility of oral cavity (the patient must be able to open atleast 2 cm)
- Uncooperative patient
- Inability to ventilate, or hypoxemia (due to time required to perform these interventions)
- Upper airway obstruction
- Pharyngeal or laryngeal trauma

Complications

- Pharyngeal or dental trauma from scope placement
- Laryngeal trauma from ETT insertion or rigid stylet
- ETT misplacement
- Prolonged intubation attempts with hypoxia

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PART VIII

Emergency Ventilation

CHAPTER 25

Esophageal-Tracheal Combitube

R. Scott Lang and Derek Davis

Concept

The Esophageal-Tracheal Combitube (ETC) is a double-lumen airway device that is used to secure ventilation through blind placement into the oropharyngeal cavity. This is a supraglottic airway that is most commonly inserted into the esophagus, but can also be blindly inserted into the trachea, though this is uncommon and usually occurs inadvertently (Fig. 25-1). Careful auscultation will allow the operator to determine whether the ETC is in the esophagus or the trachea. Tracheal insertion allows the operator to use the Combitube as a standard endotracheal tube. The ETC has two inflatable cuffs to seal the airway and allow ventilation. The proximal cuff (oropharyngeal cuff) is larger in volume and can be inflated with up to 100 cc of air, depending on the size of the Combitube. The distal cuff is smaller and is inflated in either the esophagus or the trachea with 10 to 15 cc of air, depending on the size and position of the device. The double-lumen design allows for ventilation while passing an orogastric tube through the smaller lumen to decompress the stomach. The longer of the two lumens, or the blue lumen, has side ports for ventilation within the pharynx and ends blindly. The ETC comes in a standard size (42 French) and a smaller size (37 French) for smaller individuals.

Evidence

The ETC has been used successfully as an airway for several years by trained and untrained operators for both routine and emergent airway management. It has been used for prehospital management,[1] for routine airway management for operative procedures, and during cardiopulmonary resuscitation.[2] A comparison of the ETC with the laryngeal mask airway (LMA) when used by staff not previously trained in airway management after induction of anesthesia showed that the ETC can be used successfully by untrained personnel.[3] The LMA may be a more practical device for untrained personnel when considering the extra maneuvers for placement of the ETC and its higher cost. The advantage of the ETC in the emergent setting is that it provides better protection from aspiration with its double-lumen design. There have been reports of successful use of the ETC in the intensive care setting,[4] but case reports of tongue engorgement have suggested that long-term use may increase the risk of airway complications.[5] Ischemia-reperfusion injury or compression of the glossal blood vessels were suggested as possible causes of this complication. Pressures that are up to three times higher than the mucosal perfusion pressure have been measured in properly inflated pharyngeal cuffs.[6]

Force upon insertion of the ETC should be avoided, as it may cause esophageal rupture,[7] subcutaneous emphysema, pneumomediastinum, and pneumoperitoneum.[8] A retrospective review of prehospital complications with ETC insertion reported dental trauma, inability to determine placement due to emesis through both lumens, and dislodgement during transport.[1] Though there are reported complications, the ETC continues to be used successfully as a blind insertion rescue airway device during emergent situations.

Preparation (Fig. 25-1)

- Preparation for direct laryngoscopy (see Chapter 5)
- Check pilot balloons and cuffs of ETC
- Anesthetized or unconscious patient in neutral position
- Preoxygenation is preferred; however, this device is most likely to be used when intubation and mask ventilation are impossible

Procedure (Figs. 25-2–25-6)

- Grasp lower teeth of patient with left hand, pulling upward
- Insert ETC into pharynx and advance until the pair of black lines on the tube lie on either side of the front upper incisors
- Insufflate air into the blue pilot balloon, cuff 1 (100 mL for 41 French ETC, 85 mL for 37 French ETC), and then into the white pilot balloon, cuff 2 (10 to 15 mL for 41 French ETC, 6 to 12 mL for 37 French ETC)

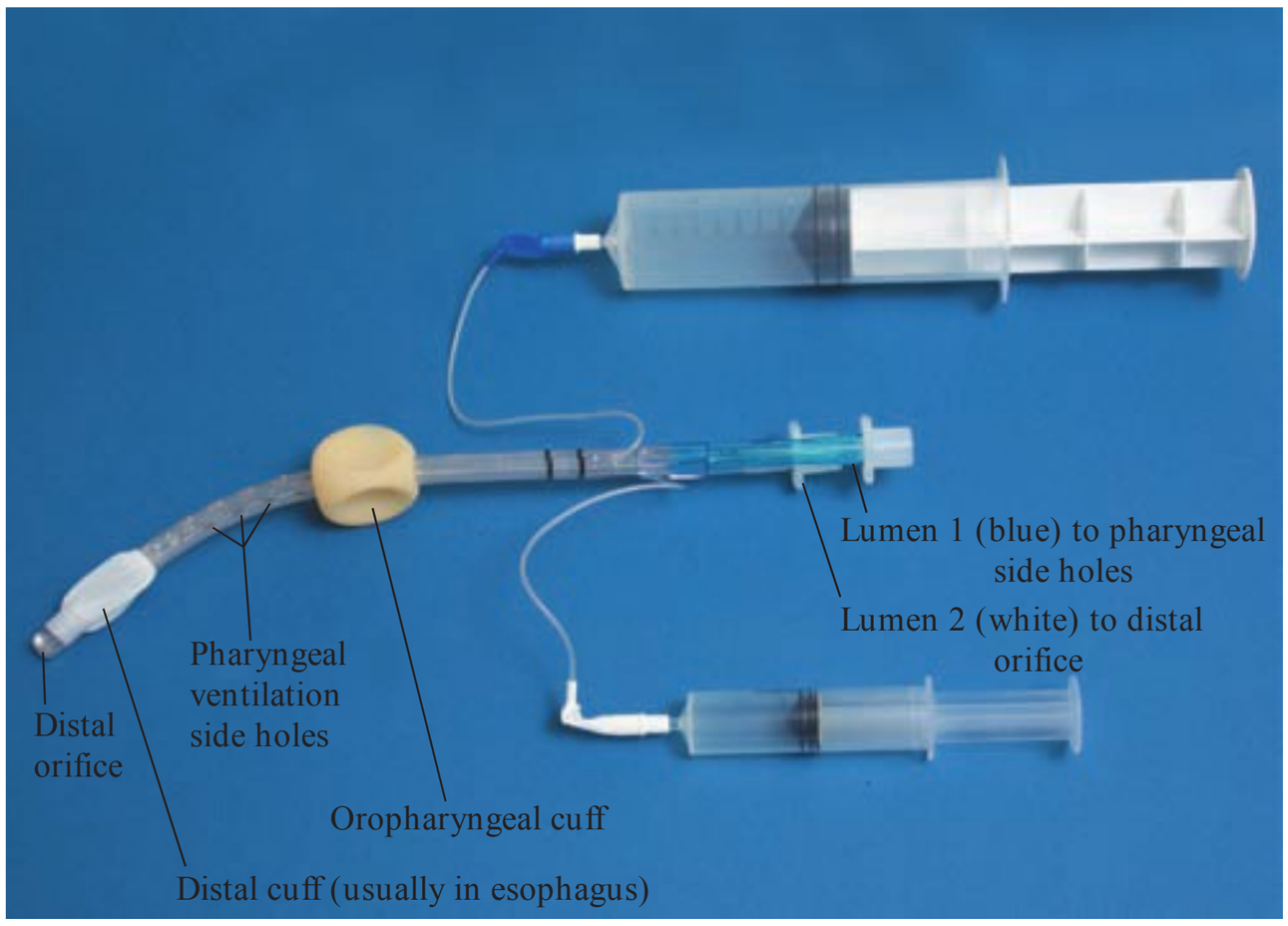


FIGURE 25-1 The ETC. Note two tubes with two cuffs, two pilot balloons, and two lumens.



FIGURE 25-2 ETC inserted into pharynx in cadaver specimen.

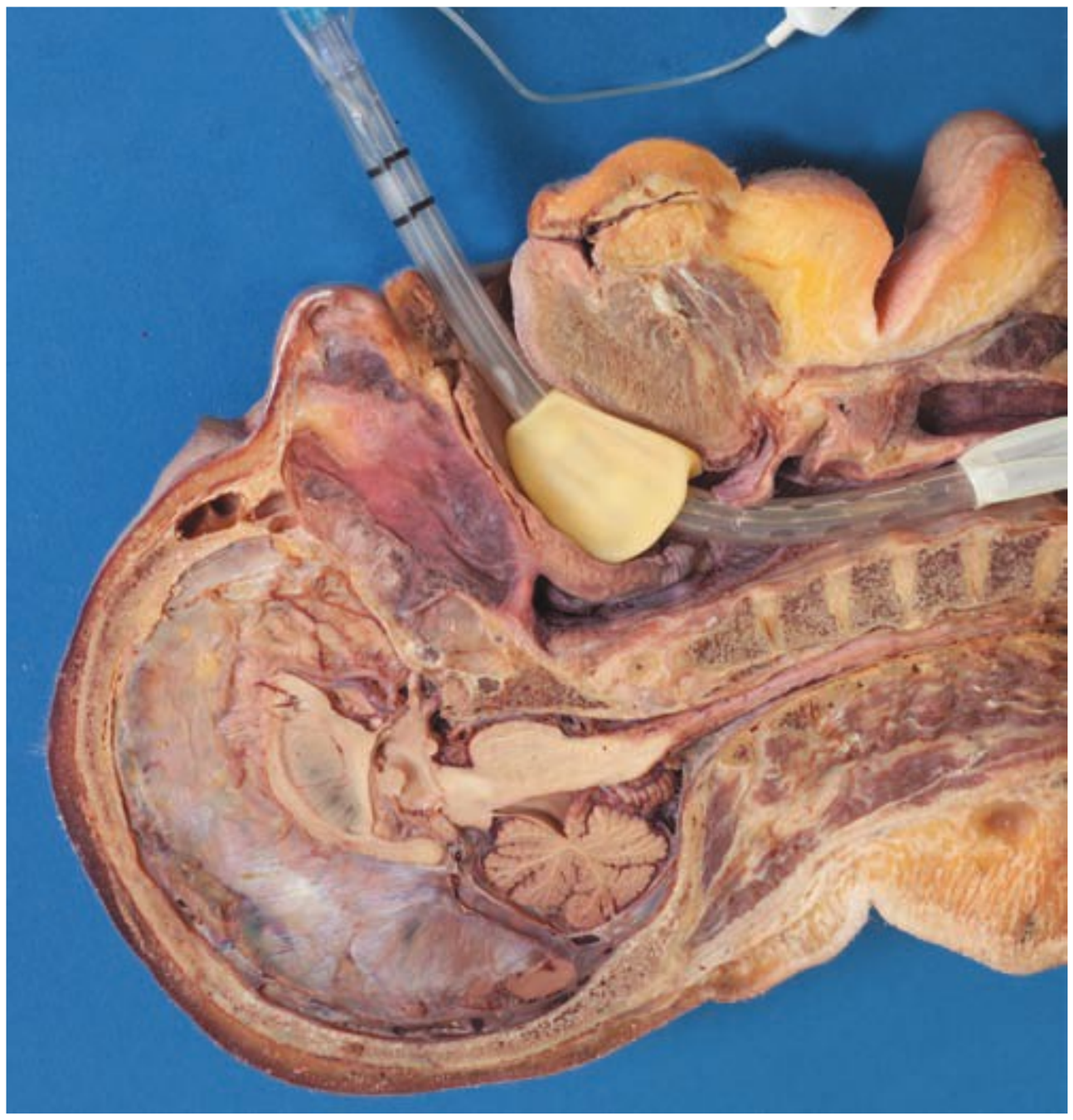


FIGURE 25-3 ETC advanced into esophagus.

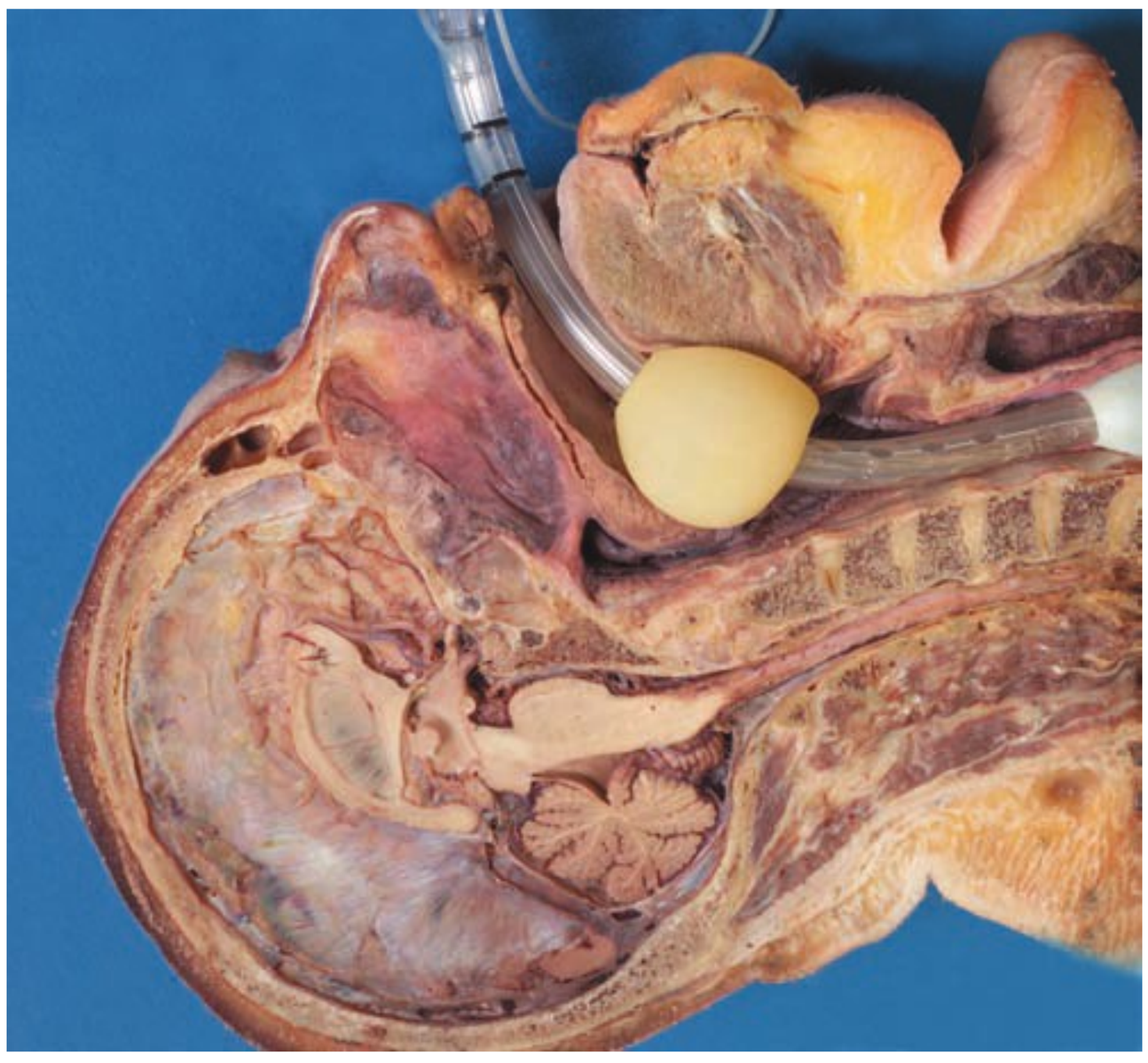


FIGURE 25-4 Cuffs of ETC inflated. Note proximity of pharyngeal side holes to glottic opening, and seal provided by distal and proximal balloons.

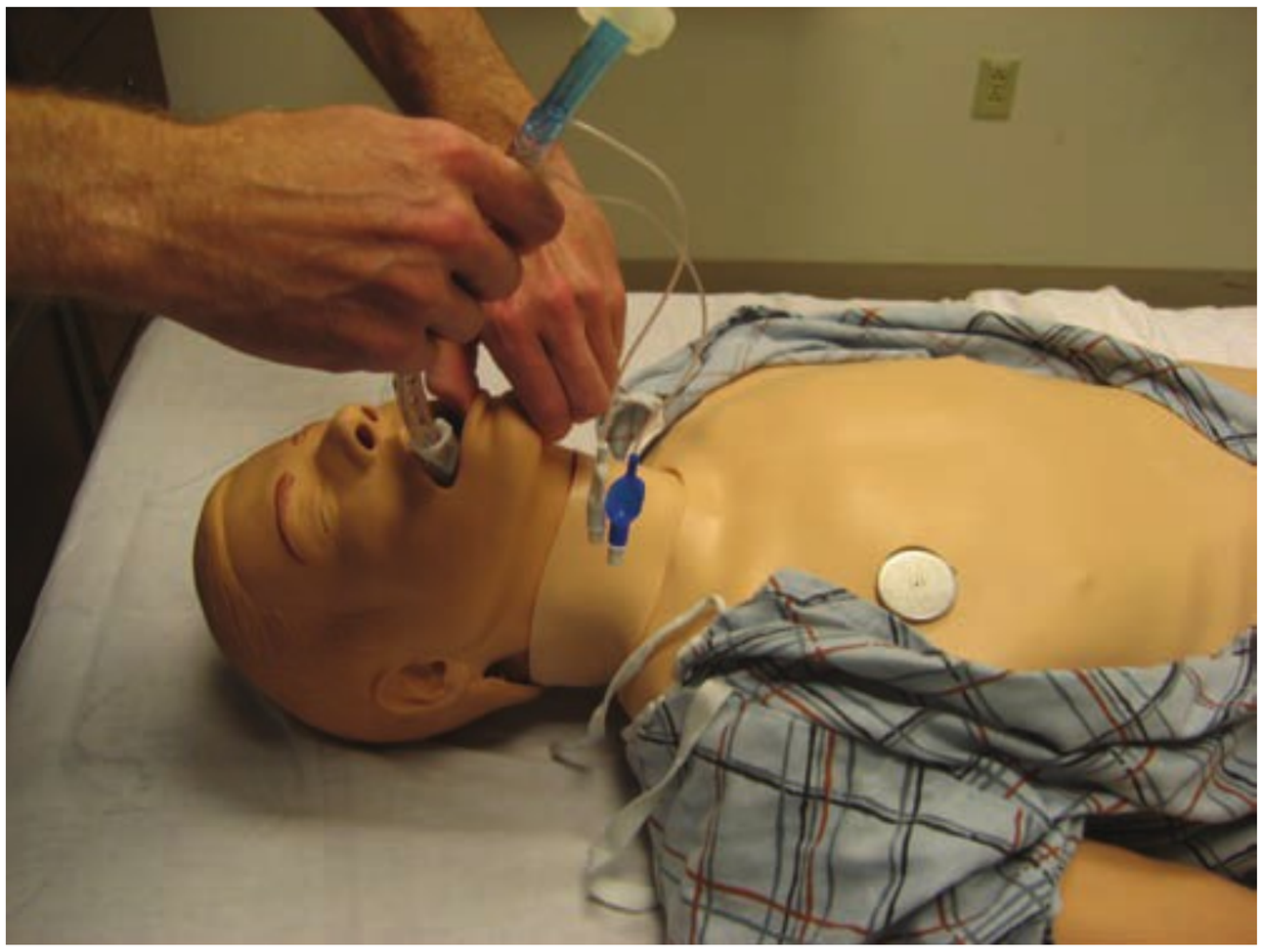


FIGURE 25-5 The head is placed in a neutral position and the mandible is pulled forward by grasping the lower teeth and chin. The mouth is opened during this maneuver. The ETC is then inserted through the pharynx into the esophagus blindly.

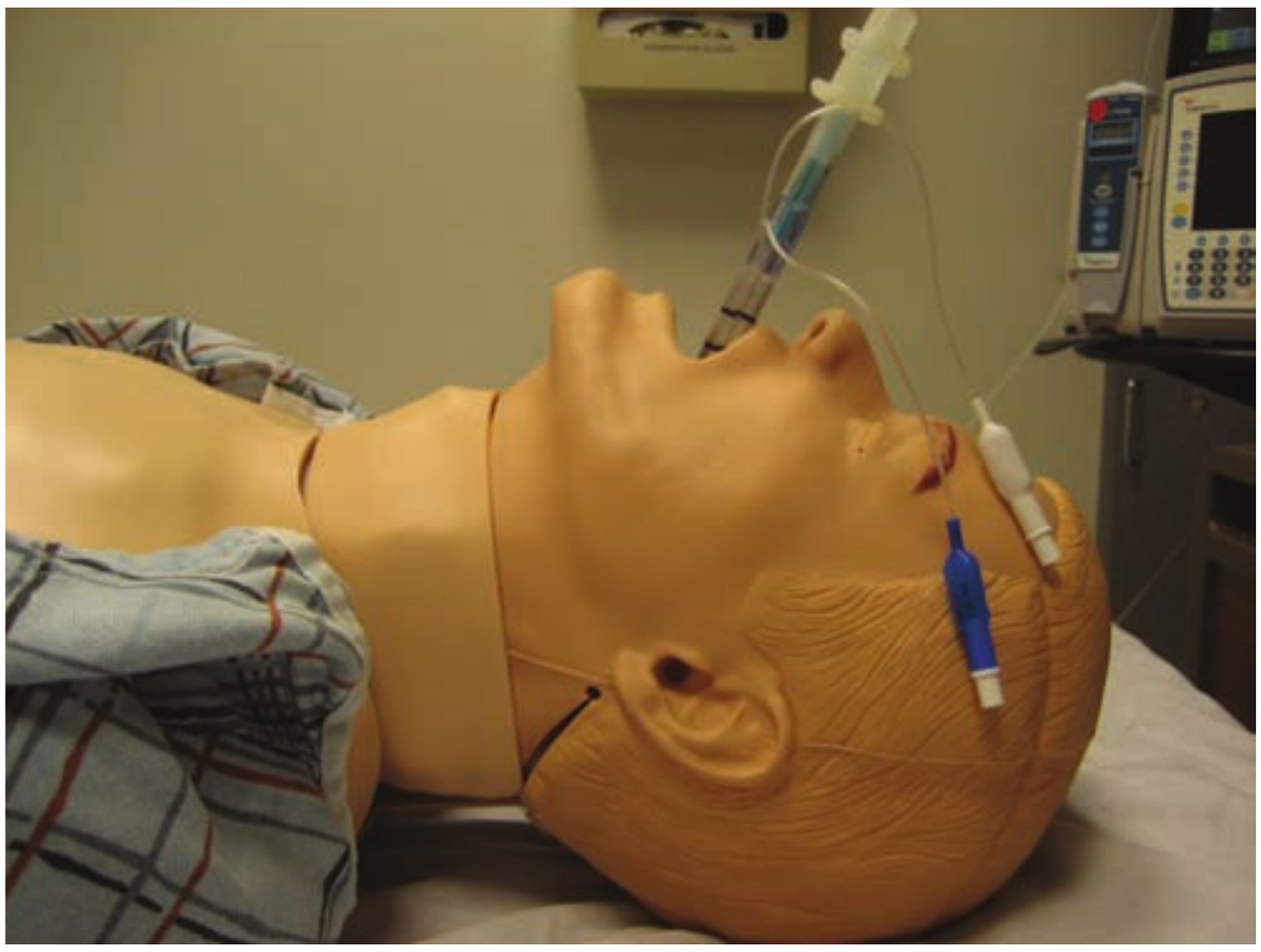


FIGURE 25-6 The device is gently pushed down until the black lines on the ETC are aligned on either side of the incisors.

- Ventilate through Lumen 1 (blue), which is the pharyngeal lumen; gas exits the side holes lying in the hypopharynx
- Check for breath sounds, chest rise, and end-tidal CO_2: if these are present, then secure the ETC
- If no ventilation is evident, begin ventilation through Lumen 2 (clear), the distal tip lumen
- Check for breath sounds, chest rise, and end-tidal CO_2: if these are present, the tube is in the trachea and should be secured and regarded as an endotracheal tube
- If there is no evidence of ventilation through either lumen, pull the ETC back slowly after deflating the cuffs, as it is probably inserted too far, and check repeatedly for evidence of ventilation. When ventilation is evident, secure the tube at that level.

Practicality

- Portable; affordable relatively easy to use; effective in managing an airway in most emergent situations

Indications

- Inability to mask ventilate
- Inability to secure endotracheal intubation
- Untrained providers or providers with limited airway management training
- Lack of intubation equipment or other airway devices
- Securing an airway blindly and decreasing risk of aspiration

Contraindications

- Esophageal injury or severe disease
- Laryngeal or pharyngeal injury
- Supraglottic obstruction (tumor, foreign body)
- Spontaneously breathing or alert patient
- Inability to access the oral cavity (trauma or any other conditions)

Complications

- Esophageal injury (rupture, laceration)
- Subcutaneous emphysema
- Pneumomediastinum
- Pneumoperitoneum
- Pharyngeal trauma
- Dental injury
- Improper positioning or dislodgement

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CHAPTER

26

Laryngeal Mask Airway

Paul G. Tarasi and Ryan C. Romeo

Concept

The laryngeal mask airway (LMA) has been in widespread use by anesthesiologists in Europe since the 1980s, when it was developed by Dr. A.I.J. Brain.[1] It is used worldwide in the operating room (OR) to ensure airway patency during general anesthesia. The device is available in both reusable and disposable forms (Fig. 26-1), and comprises a tube attached to an ovoid mask that is placed in the hypopharynx and advanced to cover the glottic opening. When inflated, the cuff of this mask provides a seal around the glottic aperture.[2] However, this seal is inadequate at high peak inspiratory pressures, and leakage of inspiratory gases is manifest, especially when pressures begin to exceed 30 cm H_2O. In elective settings, spontaneous breathing (as opposed to positive pressure ventilation) is preferred with the use of this device, but it can be used safely and effectively for positive pressure ventilation if tidal volumes and peak inspiratory pressures are kept low (tidal volume should not exceed 8 mL/kg and peak inspiratory pressures should be limited to 20 cm H_2O). Reusable LMA masks are typically made from silicone, whereas single-use devices are often constructed with polyvinylchloride; however, some single-use devices such as the AES Ultra are made with silicone. The LMA is manufactured in many sizes, ranging from those for neonates to those for large adults. In adults, the usual range of sizes is 3, 4, and 5 (Fig. 26-2). Multiple manufacturers have now begun to offer similar devices, often with functional modifications. The Ambu AuraOnce (Ambu, Ballerup, Denmark) (Fig. 26-3) is a disposable LMA with an angled tube designed to follow the natural curve of the supraglottic airway, with recent evidence suggesting increased ease of insertion compared with the original LMA design.[3,4] Several other manufacturers offer LMAs with flexible, wire-reinforced tubes for use in intraoral and other procedures that require positioning of the airway tube away from the surgical field, with less risk of LMA dislodgement or malposition.

Because the LMA does not provide an intratracheal seal, regurgitation and aspiration are potential risks of its use. This prompted the development of a version of the device that incorporates a gastric port to allow decompression of the stomach after insertion. The Proseal LMA (LMA of North America, San Diego, CA, USA) (Fig. 26-4) was designed to separate the respiratory and gastrointestinal tracts and provide higher airway sealing pressures, thus allowing dependable positive pressure ventilation. The Proseal LMA can be somewhat more challenging to insert than the standard LMA device, due to its larger size and different conformation. This device can be placed freehand, or with an optional insertion tool. A newer alternative, the LMA Supreme (LMA of North America) (Fig. 26-5) is a disposable, single-use device that incorporates a gastric port similar to the Proseal LMA, with an integral bite block and a premolded curved tube similar to the Ambu AuraOnce. Both the standard LMA and the Proseal LMA devices can be overinflated, with resultant mucosal injury.[5] Ideally, a manometer should be used to gauge the correct pressure of inflation, as recent evidence suggests that limiting cuff pressures to less than 60 cm H_2O (44 mm Hg) results in significantly less postoperative sore throat, dysphagia, and dysphonia.[6]

One relatively new supraglottic airway, the i-gel (Intersurgical Ltd, Wokingham, UK), resembles the LMA in shape and insertion technique but is made from a thermoplastic elastomer to conform to the perilaryngeal anatomy and does not have an inflatable cuff. This simplifies use and may reduce the risk of compression injury. Like the Proseal LMA and the LMA Supreme, this airway also incorporates a gastric channel. It is available in three adult sizes.

Evidence

The LMA is effective for ventilation in the OR during many types of elective surgical cases.[1,2] Originally used mainly for cases in the supine position, recent evidence suggests that the LMA may be a useful airway tool for elective cases in the prone position as well.[7–9] The LMA has also been used as an emergency ventilation adjunct in various circumstances.[2,10,11] It can be used effectively as a "bridge" to fiberoptic intubation, because a size 6.0 endotracheal tube (ETT) (or 7.0 in the size 5 LMA) may be passed through the LMA and into the glottis, while the lumen of the device effectively guides the fiberscope to the laryngeal opening.[11,12] The LMA has proven useful as a both an alternative to bag-valve-mask (BVM) ventilation

in cardiopulmonary arrest and as a rescue device in difficult airway management. Among intensive care nurses, Martin[13] found that the LMA proved easier to use and provided superior tidal volumes with less likelihood of airway obstruction than BVM ventilation with or without an oral airway. When untrained volunteers were assessed for the ability to ventilate patients under general anesthesia, Alexander[14] described marked improvement in the success of ventilation and oxygenation when the LMA was used, compared with BVM ventilation. He reported a 43% rate of failure to ventilate effectively with the latter device, whereas the LMA was successful in all but 13% of cases. Likewise, Smith[15] found that anesthetists were better able to maintain oxygen saturation and a patent airway in 64 patients under general anesthesia randomly assigned to ventilation using the LMA as opposed to a face mask.

In an evaluation of the utility of LMA for prehospital care, Pennant[16] described placement of LMA by paramedics in 100% of cases in less than 40 seconds, whereas ETT placement took more than twice that long and resulted in 31% misplacement. Davies[17] described placement of an ETT or LMA in a mannequin model by paramedics with little training: 94% of LMA insertions were successful, compared with only 51% of ETT insertions.

The LMA has been well established for effectiveness during difficult airway management in the OR.[10–12] Experienced practitioners can usually insert the LMA within 20 seconds, with a success rate of 98%.[18] Parnet[19] described the use of LMA as the adjunct of first choice by academic anesthesiologists facing difficult intubation or difficult ventilation situations in 17 cases over 2 years, with a 94% success rate, whereas other modalities were significantly less successful. Very few reports exist describing failure of an LMA in a cannot intubate, cannot ventilate (failed airway) situation.[20] Thus the considerable experience with the LMA in unexpectedly difficult airway management in the OR substantiates its use when emergent ventilation is required in other settings, such as the emergency department or intensive care unit, because it can be inserted so quickly and with a high expectation of success.[21] Its use may allow progression to a more definitive airway, whether translaryngeal or surgical, in a controlled and orderly manner, as opposed to a frenetic procedure in a severely hypoxemic patient. Given its utility in emergency circumstances, the LMA has become the intervention of choice for the cannot intubate, cannot ventilate situation in the OR, as directed by the 2003 difficult airway management guidelines of the American Society of Anesthesiologists.[22]

Various case reports of gastric aspiration related to LMA use have been published.[23] Several of these patients had predispositions to regurgitation due to obesity, surgical position, or emergency procedures. In a large meta-analysis of the literature, Brimacombe[24] concluded that the incidence of reported aspiration of gastric contents with the use of the LMA device was no higher than that reported with the use of the ETT in the elective surgical patient.

The Proseal LMA provides a higher sealing pressure than the standard LMA, facilitating mechanical ventilation, and allows passage of a gastric tube to decompress the stomach, offering a measure of protection against aspiration.[25] Like the LMA, it has proven effective in management of the difficult airway and for rescue in cannot intubate, cannot ventilate situations.[26] Failure of placement with the device may be as high as 4%.[27] Proseal LMA

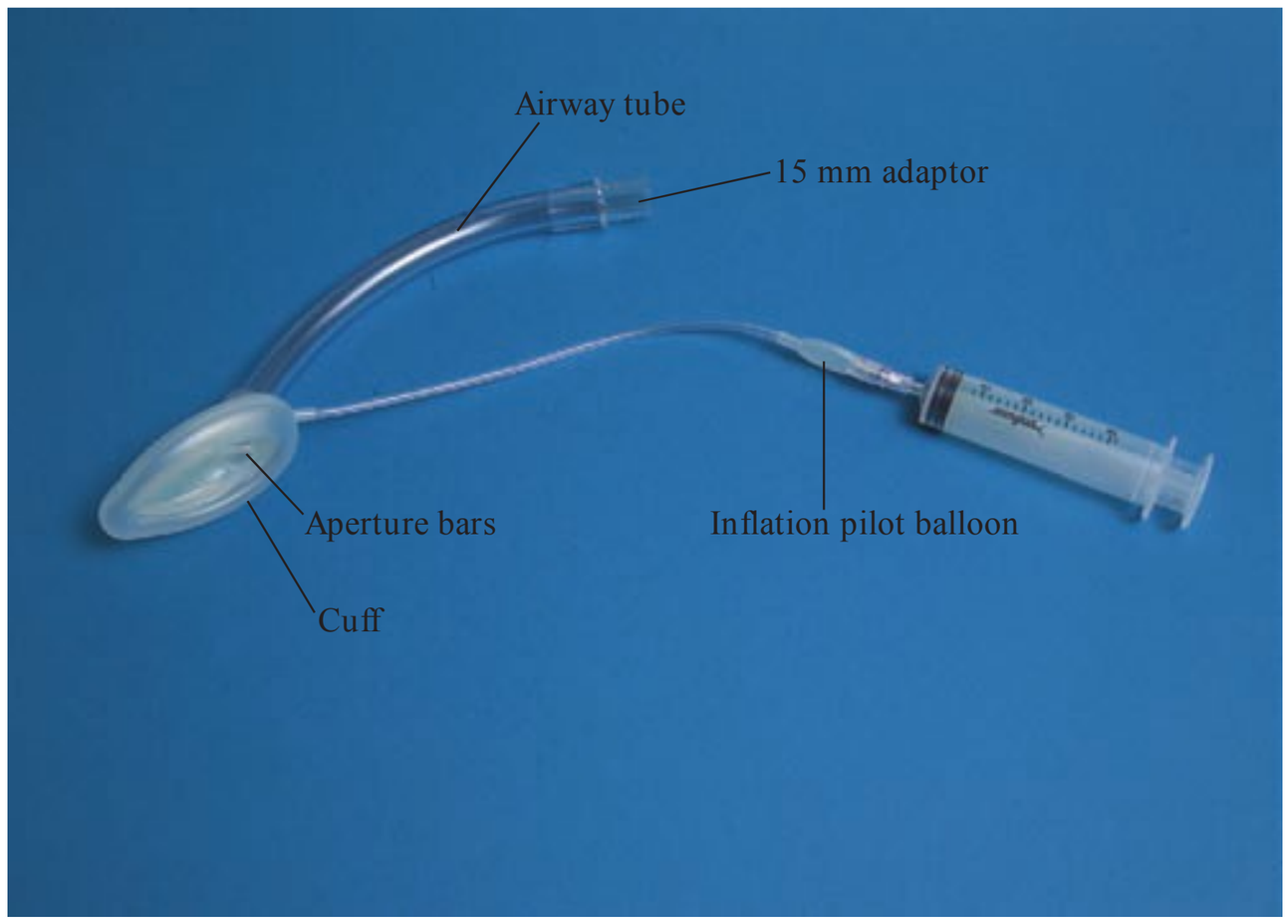


FIGURE 26-1 LMA Unique (single-use).



FIGURE 26-2 LMA Unique in sizes 3, 4, and 5 (for patients less than 50 kg, 50 to 70 kg, and greater than 70 kg, respectively). Note the aperture bars at the distal end of the airway tube, to prevent tube occlusion by the epiglottis.

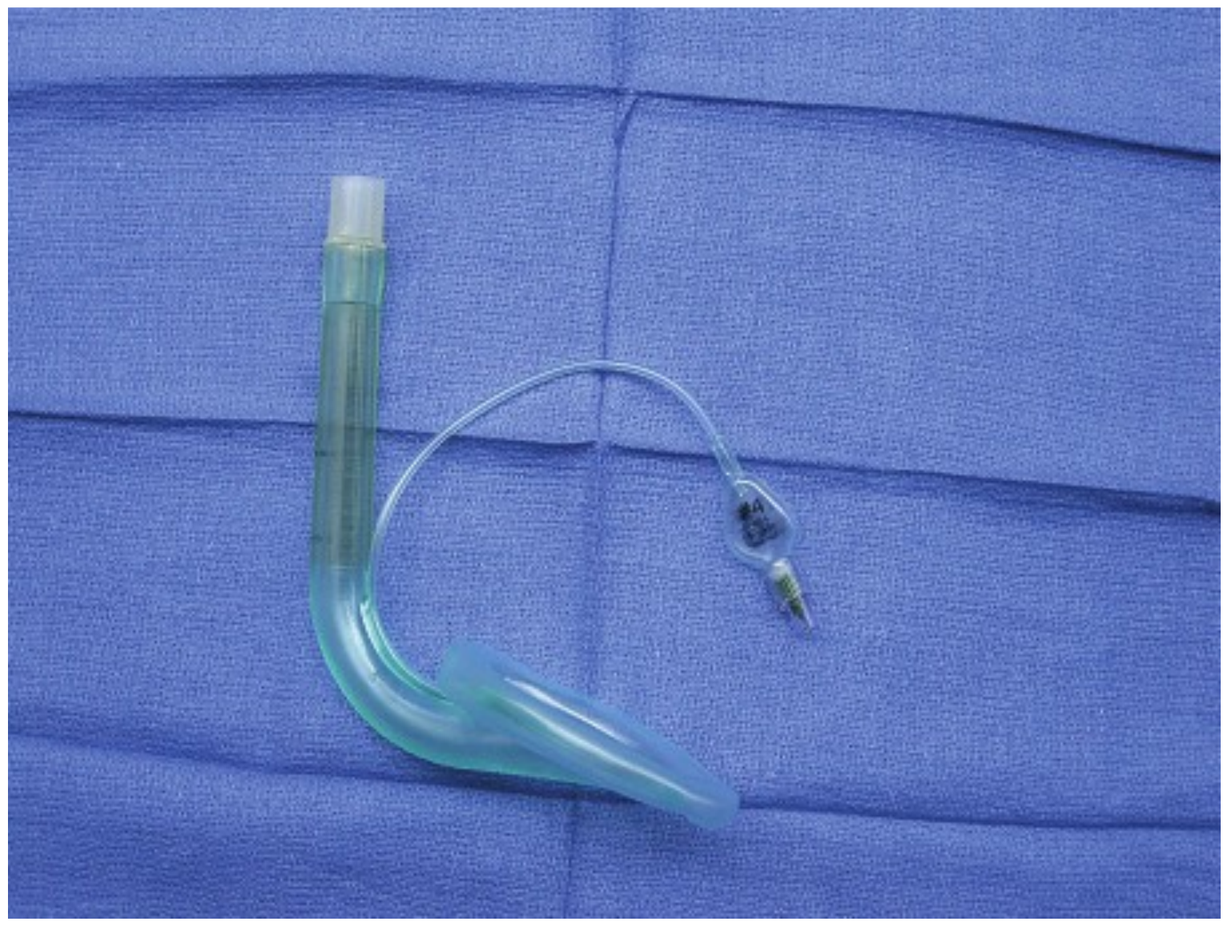


FIGURE 26-3 Ambu AuraOnce (single-use, curved airway tube).

is offered in two pediatric sizes (2 and 3), and has been demonstrated to provide a more effective seal with less gastric insufflation than the standard LMA in a population of 30 children (10 to 21 kg).[28]

Preparation for Insertion

- Preparation for direct laryngscopy (see Chapter 5)
- Estimate size of LMA necessary, based on patient size, weight (see Table 26-1)
- Lubricate dorsal (top) surface of LMA
- Check integrity of cuff and deflate completely
- Anesthetized or unconscious patient in neutral position
- Preoxygenation is optimal (but in cannot intubate, cannot ventilate scenarios will be impossible)

Procedure for Insertion of LMA (Figs. 26-6–26-14)

- Open mouth, extend head with nondominant hand
- Slide the dorsal surface of the LMA along the hard palate of the patient
- Hold the device like a pencil in the right hand, with index finger between the tube and mask at its base
- Use index finger to guide LMA into pharynx, initially exerting force cephalad, against the hard palate



FIGURE 26-4 Proseal LMA (note gastric port).
(Courtesy of LMA North America, Inc.)



FIGURE 26-5 LMA Supreme (single-use, note gastric port and curved tube).
(Courtesy of LMA North America, Inc.)

Table 26-1

LMA Sizes and Inflation Volumes

Size of LMA Device	Weight of Patient	Maximum Inflation Volume (mL)[a]
1	Infants to 5 kg	4
1.5	5–10 kg	7
2	10–20 kg	10
2.5	20–30 kg	14
3	30–50 kg	20
4	50–70 kg	30
5	70–100 kg	40
6 (LMA Classic only)	>100 kg	50

[a]The manufacturer recommends that cuff pressures do not exceed 60 cm H_2O. In sizing, the largest size that fits readily into the patient's pharynx should be chosen and inflated until there is no leak at 20 cm H_2O inspiratory pressure.



FIGURE 26-6 LMA insertion: dorsal surface pressed against the hard palate as LMA is advanced toward pharynx, in cadaver specimen.

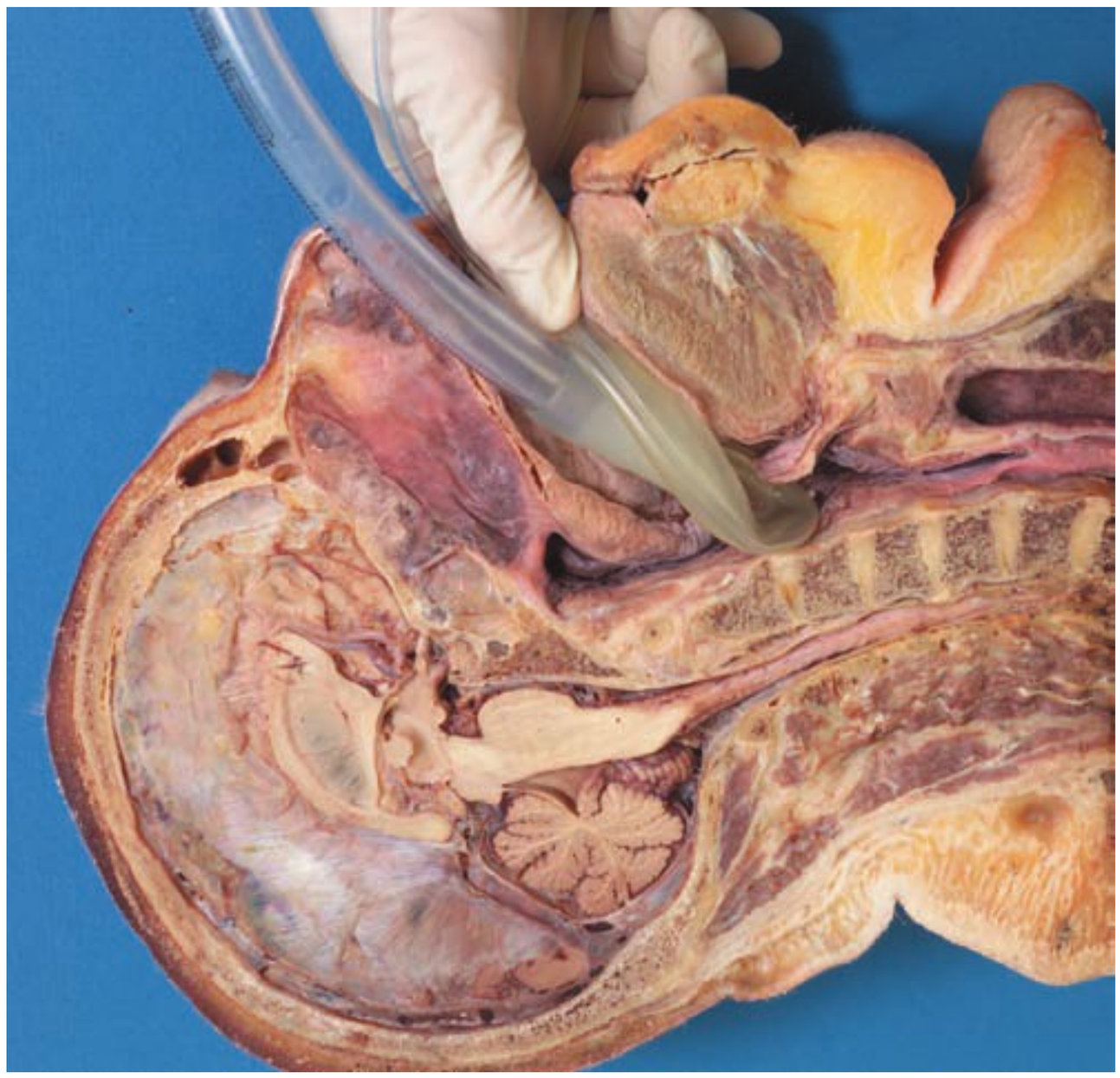


FIGURE 26-7 LMA is advanced into the pharynx.

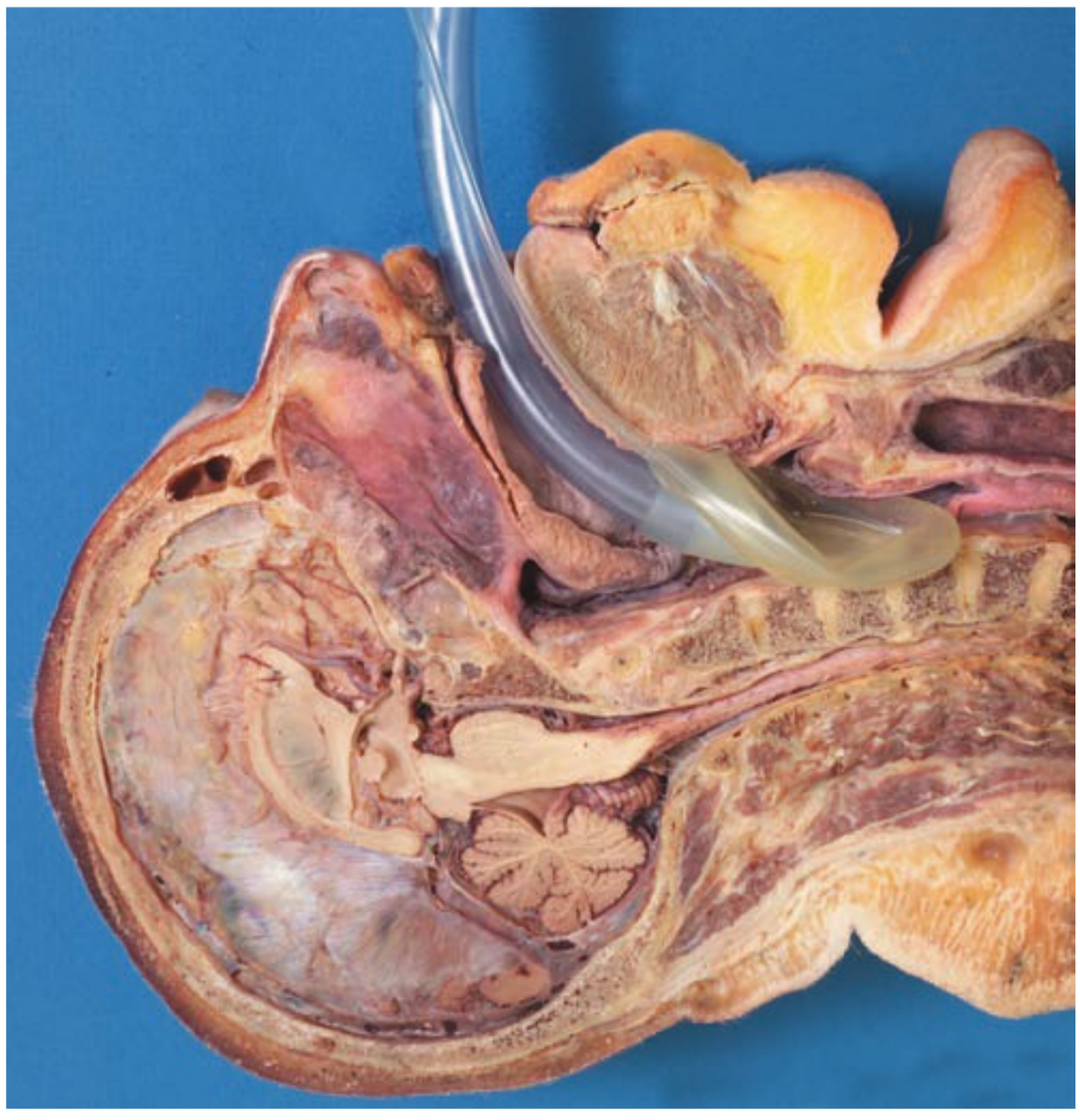


FIGURE 26-8 LMA in place over larynx.

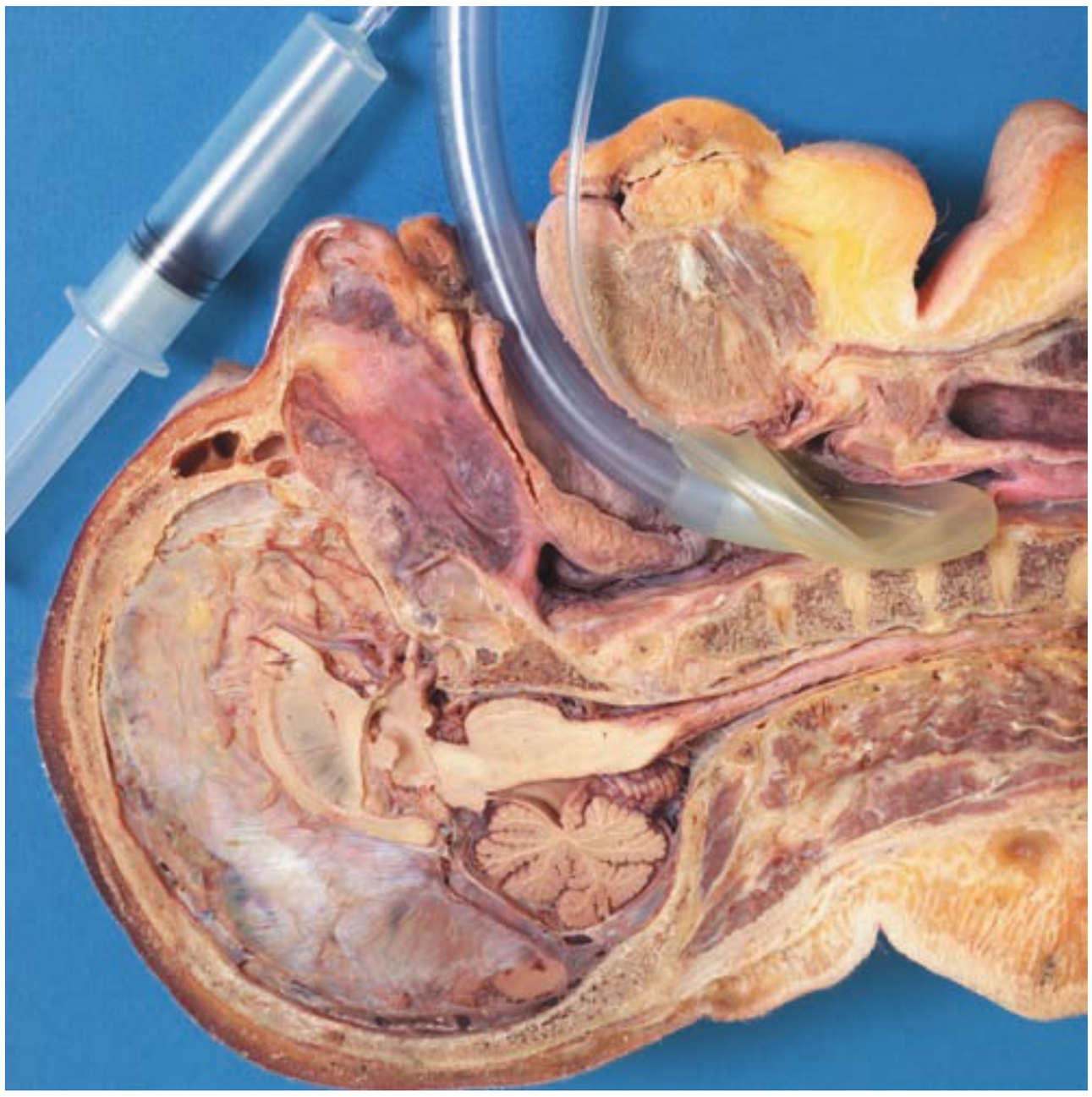


FIGURE 26-9 The cuff is now inflated to create a seal around the larynx.



FIGURE 26-10 Preparing to insert the LMA.

- The index finger continues to exert force, assisting in the acute bend that the mask and tube must negotiate to seat in the hypopharynx
- Advance LMA into hypopharynx until resistance is felt
- Inflate the cuff (volume of air depends on the LMA size)
- Confirm chest rise, breath sounds, end-tidal carbon dioxide ($ETCO_2$)
- Secure the device



FIGURE 26-11 Insertion of LMA in elective situation in OR. Note position of index finger to guide the device along the hard palate and into the hypopharynx.



FIGURE 26-12 Continue insertion until resistance is met as LMA seats in hypopharynx.

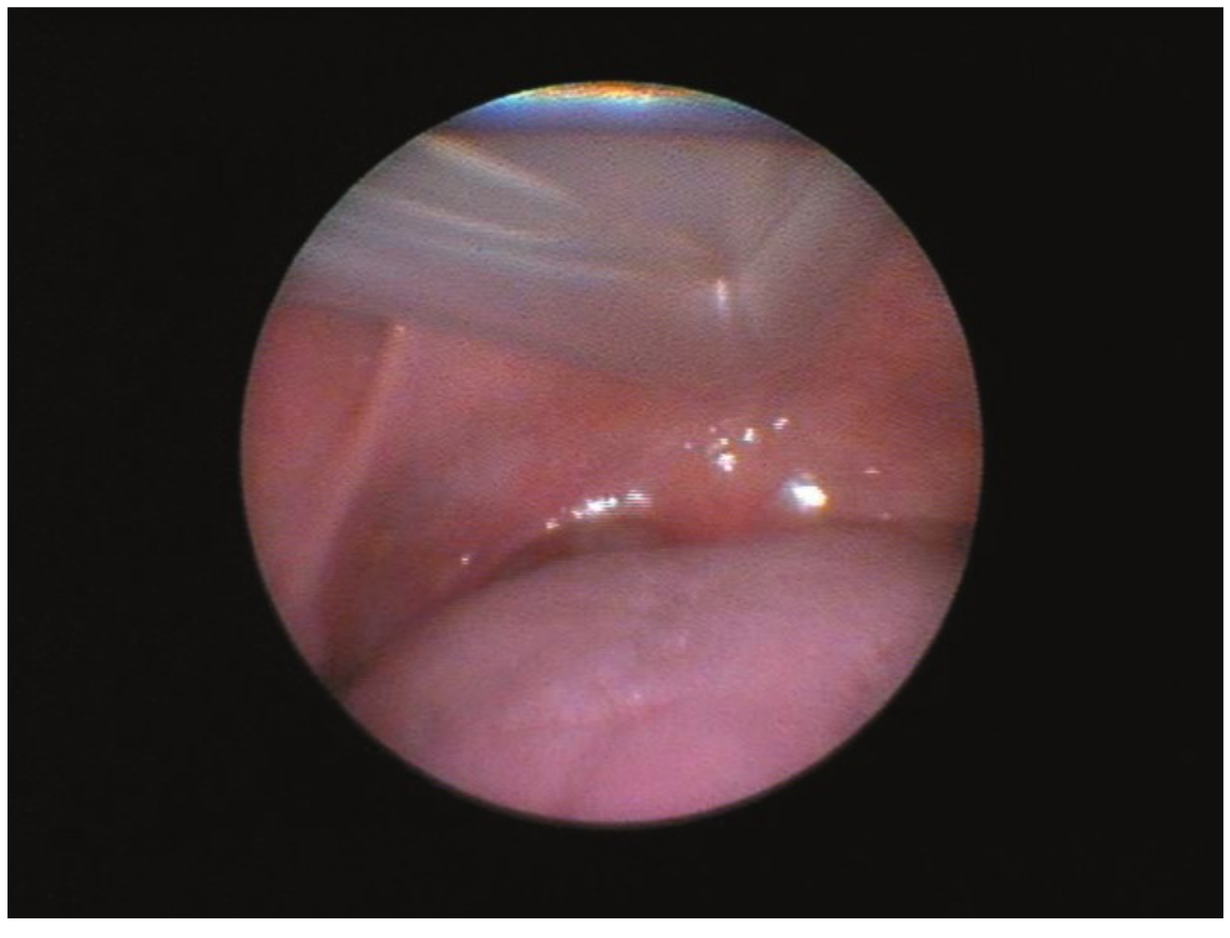


FIGURE 26-13 LMA sliding along hard palate as it is introduced toward the pharynx.

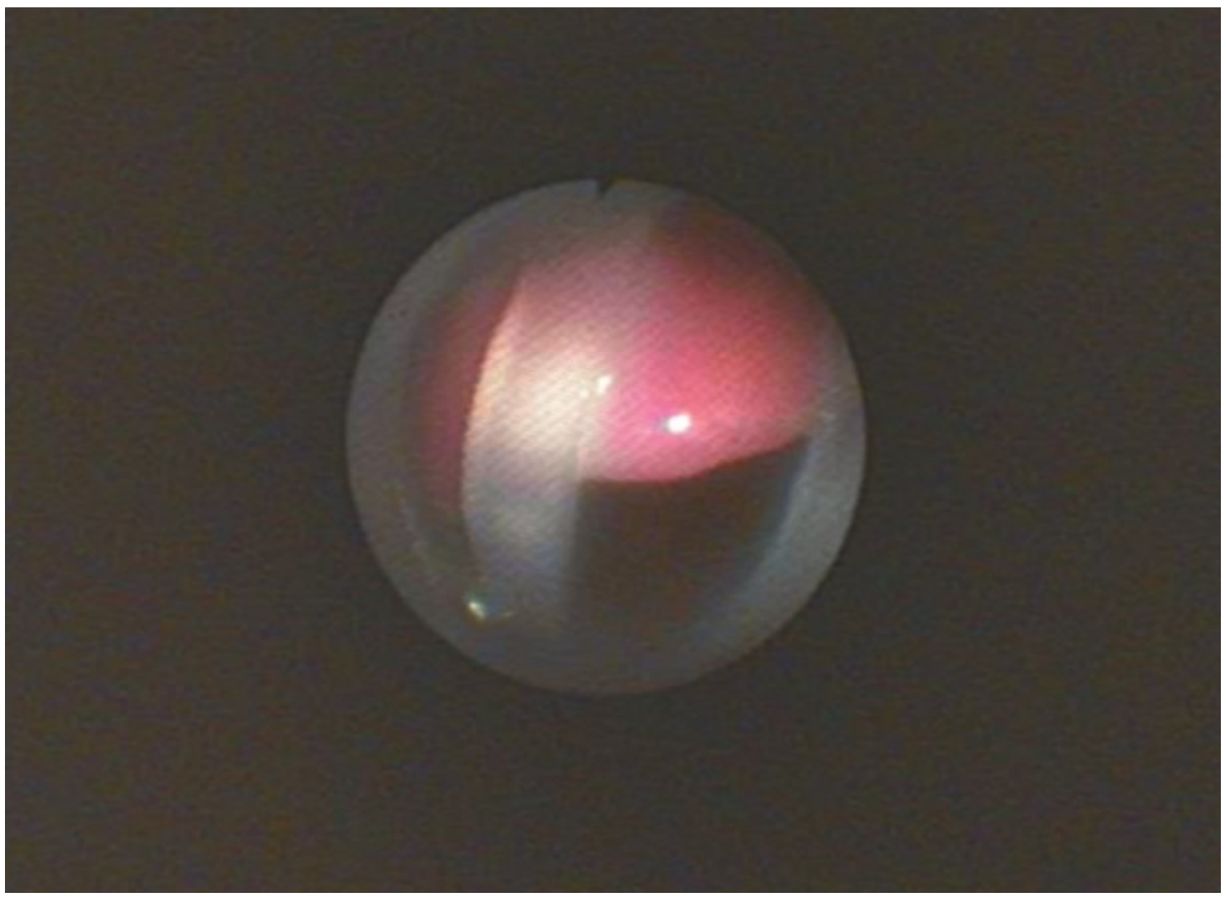


FIGURE 26-14 Bronchoscopic view inside lumen of LMA showing epiglottis just beyond grill at the end of LMA lumen (epiglottis not folded down).

Procedure for Insertion of LMA with a Fixed Curve in the Airway Tube

- Prepare as above
- Ensure that the mouth is fully opened
- Place the tip of the LMA against the inner surface of the upper teeth/hard palate
- Using a circular motion, advance the LMA along the hard and soft palates until resistance is felt

Practicality

- Inexpensive
- Portable and simple
- Relatively unfamiliar for those not using it routinely; requires use and practice for facility

Indications

- Routine airway in OR
- Difficult laryngoscopy
- Difficult ventilation
- First choice in OR for cannot intubate, cannot ventilate scenario
- Planned bridge to fiberscopic intubation

Contraindications

- Severe upper airway obstruction
- Inaccessibility of oral cavity
- Full stomach or potential for gastric regurgitation (this applies to elective use of the device)
- Planned positive pressure ventilation if peak airway pressures are likely to exceed 20 cm H_2O

Complications

- Regurgitation/aspiration of gastric contents
- Failure to seal over the glottis, with inadequate ventilation
- Gas leak at high peak inspiratory pressures (about 30% of tidal volume is lost at inspiratory pressures greater than 30 cm H_2O)
- May stimulate swallowing, cough, or hiccups when inserted
- Laryngospasm
- Pharyngeal trauma during blind insertion
- Nerve injury due to compression (CN IX, X, XII)
- Overinflation of cuff with pharyngeal mucosal injury

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CHAPTER

27

Intubating Laryngeal Mask Airway

Ryan R Wilson and William McIvor

Concept

The intubating laryngeal mask airway (ILMA) (Fastrach, LMA of North America, San Diego, CA, USA) is a derivation of the laryngeal mask airway (LMA) that facilitates both ventilation and blind endotracheal intubation. The device has several features that distinguish it from the standard laryngeal mask device. The intubating laryngeal mask consists of a soft mask that fits over the larynx, attached to a rigid stainless steel tube. The lumen of the tube has a larger internal diameter than the standard LMA and is attached to a handle to facilitate insertion. This tube admits a flexible, reinforced endotracheal tube (ETT) specifically manufactured for this laryngeal mask. The device comes in three sizes for adults (3, 4, and 5), all of which can admit a range of ETT sizes, up to size 8.0. Other manufacturers have begun to offer similar devices, such as the Air-Q Reusable Laryngeal Mask (Mercury Medical, Clearwater, FL, USA) and Ambu Aura-I (Ambu Inc., Glen Burnie, MD, USA). Both provide a means of intubation through the device but do not have the steel barrel, handle, or epiglottic elevating bar (EEB), which are features of the ILMA.

Evidence

The ILMA device has proven useful for managing the difficult airway in various settings. The popularity of the LMA in Europe and around the world has led to ready acceptance of the ILMA. The ILMA is relatively easy to use. Those with limited airway management experience may be more successful with the ILMA than with conventional methods. Timmerman et al[1] showed that medical students ventilate and intubate quicker and more effectively via ILMA than by conventional bag-mask ventilation and laryngoscopy. Thirty medical students, each intubated three patients using each method. Ventilation was significantly more successful with the ILMA (97.8% vs 85.6%). Intubation was also more successful using the ILMA (92.2% vs 40.0%). In Australia, Agro[2] described its use in 110 patients slated for general anesthesia, with 95% success. However, the authors encountered resistance to ETT insertion in 60% of patients, which required some form of adjustment. The average time required for the authors to intubate patients was 79 seconds. In a multicenter study from the United Kingdom, Baskett[3] assessed the efficacy of the ILMA in intubation of 500 patients undergoing general anesthesia, with 95% success in ventilation through the mask portion of the device. The authors had 80% intubation success on the first attempt, with 4% of patients requiring three attempts, and an overall failure rate of 4%. Brain[4] used the ILMA in 150 patients undergoing general anesthesia, with successful ventilation of all patients. In half of the patients, resistance to ETT insertion through the device occurred, requiring one of several described "adjusting maneuvers" before intubation was accomplished. The study included 13 patients with potential or known difficult airway anatomy, all of whom were intubated successfully. Four different adjusting maneuvers were suggested (Table 27-1),

Table 27-1

Adjustment Maneuvers for Blind Intubation through the ILMA[3]

Depth of Resistance	Likely Cause of Resistance	Corrective Action
0.0–1.5 cm	EEB trapped behind cricoid cartilage	Replace ILMA with next smaller size
1.5–2.0 cm	Epiglottis folded down over glottis	Remove ETT, swing ILMA back out, up to opening 6.0 cm (with cuff up), replace in pharynx
2.0–4.0 cm	EEB lying too high	Replace ILMA with next larger size
4.0–6.0 cm	ETT tip wedged between mask tip and cricoid cartilage	Replace ILMA with small size

depending upon the depth at which resistance to the ETT advancement was encountered.[3]

In 38 patients with known difficult airway anatomy (based on patient history or physical examination), Joo[5] assessed the utility of the ILMA compared with awake intubation with the fiberoptic bronchoscope (FOB). All awake FOB attempts were successful, but only half of the patients could be intubated blindly with the ILMA. The other half required use of a bronchoscope, and 10% required involvement of a second operator to place the ETT. In another evaluation of this device in patients with known or suspected difficult airways, Ferson et al[6] evaluated the utility of the ILMA in 257 patients: 78% after induction of anesthesia, and 20% awake, with topical anesthesia (in 2% of cases, patients were unconscious and no anesthetic was provided). The authors were able to successfully ventilate all of these patients, and ETT insertion was accomplished blindly in 96.5% of the 200 in whom it was attempted (the remainder were intubated with FOB, using the ILMA as an introducer device), 75% on the first attempt.

In a study of the efficacy of the ILMA in obese patients, Combes et al[7] found that the device required less adjusting maneuvers and fewer attempts at blind placement than in lean subjects, with similar overall intubation success rates (96% vs 94%, respectively). Among anesthetized patients where in-line cervical immobilization was used to simulate cervical spine trauma, Komatsu et al[8] found that the ILMA was simpler and quicker to insert than another supraglottic ventilation device, the laryngeal tube, and allowed ventilation with larger tidal volumes. Other case series also indicate that the ILMA can be used safely in patients with cervical spine injuries or disorder.[9,10] In a retrospective review by Ferson et al,[6] 70 patients with known unstable c-spines and immobilized with rigid collars were successfully intubated blindly using an ILMA with a 92.6% success rate on the first attempt. In five cases (7.4%), two attempts were needed. FOB assistance was used electively in two of the five cases for the second attempt. The use of the ILMA was not implicated in any new neurologic deficits in these patients.

Less data exist related to use of the ILMA in emergency intubation, outside the operating room (OR). Asai,[11] simulating trauma resuscitation with manual in-line immobilization of the cervical spine in anesthetized patients, evaluated the ILMA for intubation in 40 patients. The ILMA was used in conjunction with FOB to ensure correct placement, and this tandem was compared with direct laryngoscopy with use of a bougie. The authors reported 85% success of intubation with the ILMA under these circumstances, compared with less than half of the patients in the laryngoscopy-bougie group being successfully intubated with these conditions. Rosenblatt[12] reported three cases of successful intubation with the ILMA in patients in whom direct laryngoscopy had failed in the emergency department. The authors commented that "proficiency in its [ILMA] use requires practice under controlled conditions" and suggested that "the emergency physician seek out elective practice" before it is used for airway management under emergent circumstances.

Use of the ILMA for out-of-hospital difficult airway management by anesthesia-trained emergency physicians was investigated by Timmerman et al.[13] They reported successful ventilation and intubation using the ILMA in all 11 patients upon whom it was employed, including in 8 patients in whom either blind nasal or oral intubation had failed. Busch et al[14] reported 97% successful ventilation and 86% successful intubation using the ILMA by untrained field emergency nurses in out-of-hospital cardiac arrest situations. They concluded that the ILMA was an effective alternative to direct laryngoscopy for endotracheal intubation in difficult airways outside the hospital by untrained personnel.

Preparation (Figs. 27-1 and 27-2)

- Preparation for direct laryngoscopy (see Chapter 5)
- Estimate size of ILMA necessary for patient, based on size and weight
- Lubricate both ILMA (dorsal cuff) and the reinforced ETT
- Check cuff of both ILMA and ETT
- Place ETT through LMA to ensure smooth function and lubrication
- Anesthetized, preoxygenated patient, in neutral or sniffing position

Procedure for Intubation with Intubating LMA (Figs. 27-3–27-17)

- Open mouth, place the ILMA into the pharynx using the handle to rotate the mask into the hypopharynx until resistance is felt
- Inflate ILMA cuff, confirm optimal ventilation
- Stabilize ILMA and insert ETT through it with longitudinal black stripe facing cephalad
- When black band on ETT (15 cm from the tip) reaches the proximal lumen of LMA device, the tip of the ETT is at the EEB at the distal end of LMA lumen
- Advance ETT, lifting gently on the handle of the ILMA device
- If resistance is encountered, note depth and use adjusting maneuvers as necessary (see Table 26-1)
- When ETT advances smoothly with no resistance, inflate ETT cuff

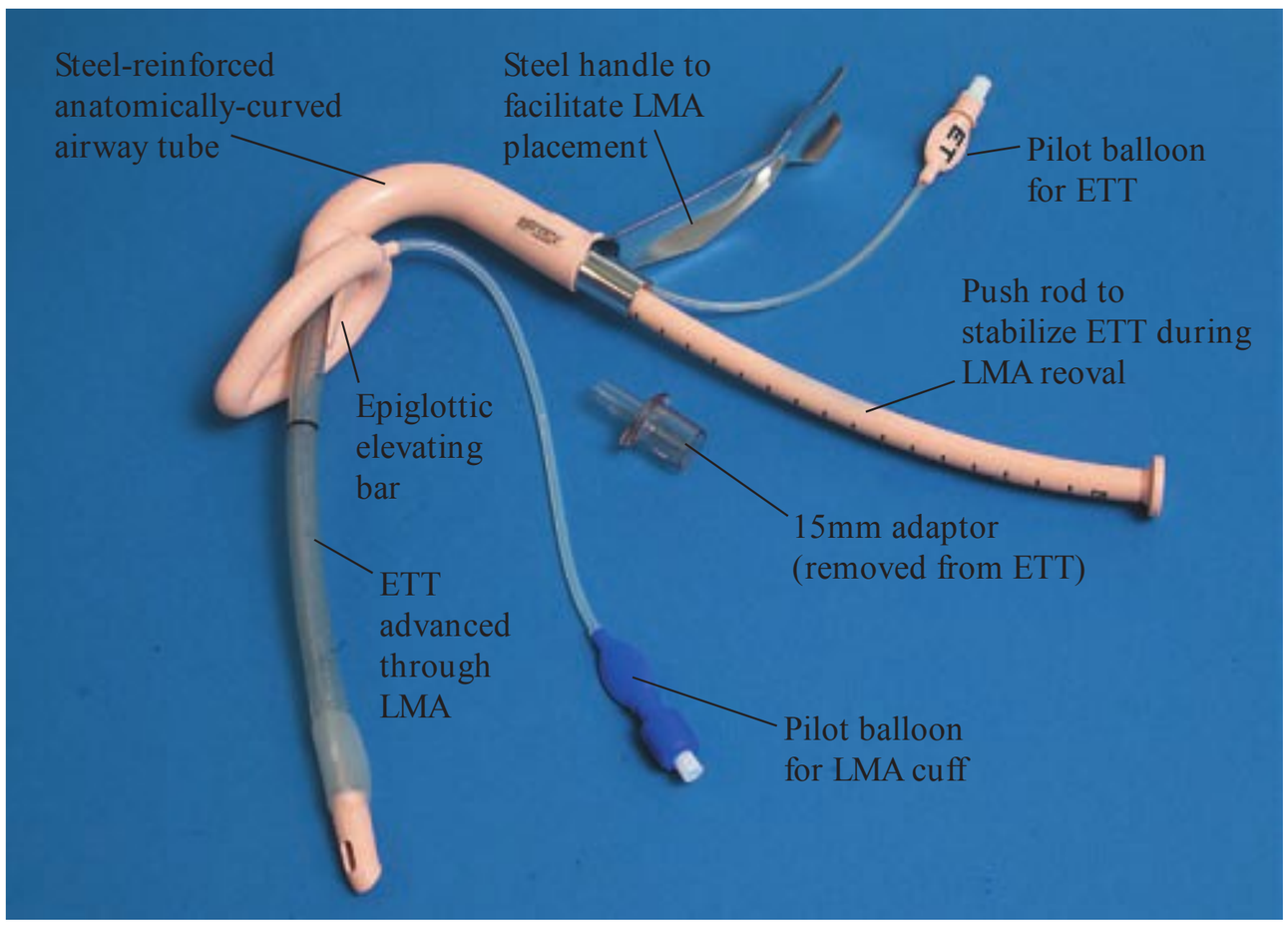


FIGURE 27-1 The intubating LMA and its push rod and dedicated ETT.

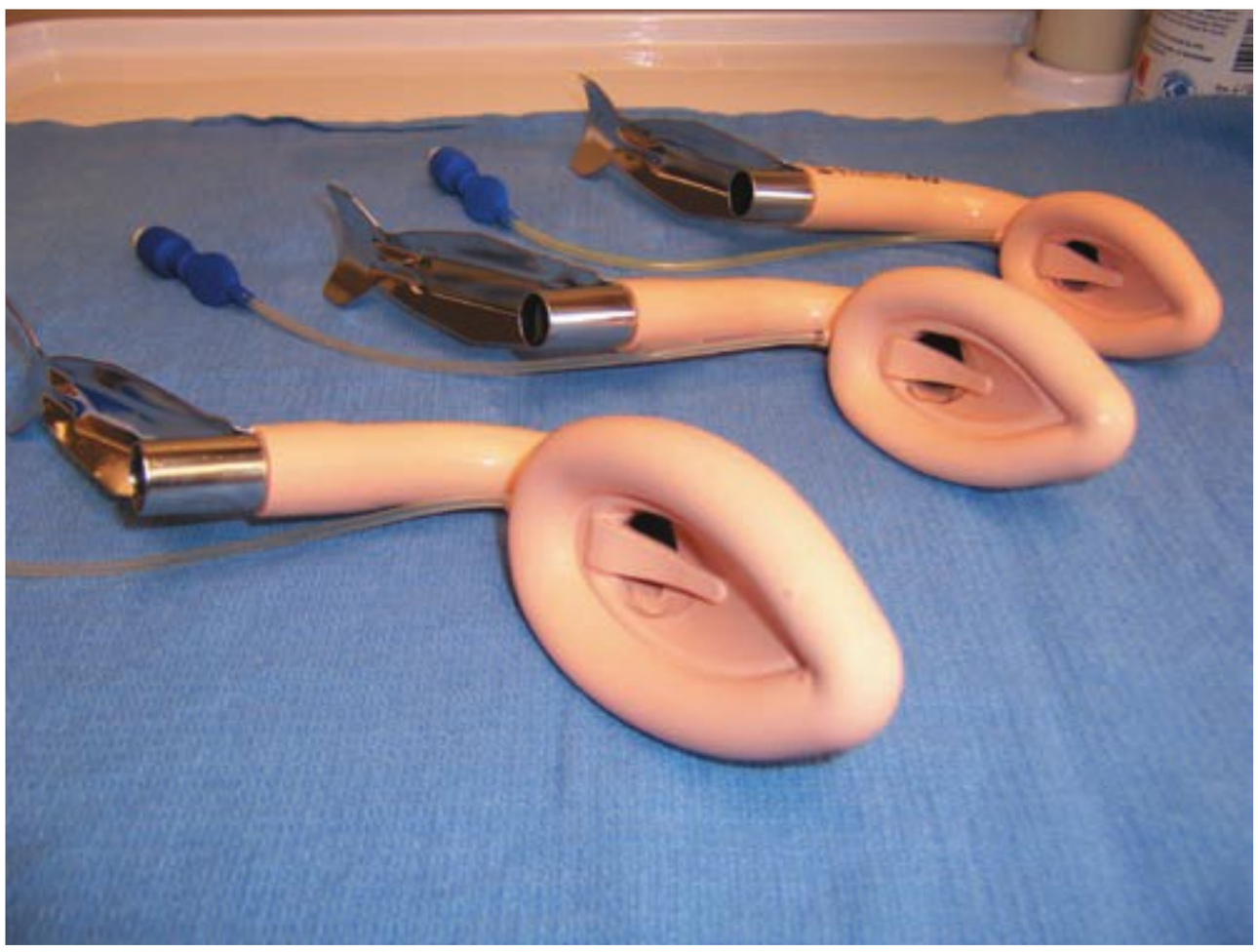


FIGURE 27-2 ILMA in three sizes for adults.

- Ventilate patient and confirm ETT position
- Remove 15-mm adaptor from the ETT, deflate ILMA, and remove it using the push rod
- Grasp ETT with fingers (or Magill forceps) when it is visible or palpable, continue LMA removal
- Reattach 15-mm adaptor to ETT, begin ventilation, and reconfirm ETT position
- Secure ETT

Practicality

- Reasonably expensive ($1,500 for three adult sizes)
- Portable
- More complex than standard LMA: ETT insertion requires multiple attempts at times; adjustment maneuvers must be well understood and removal of LMA without moving ETT can be awkward. Bear in mind that, depending on the clinical scenario, removing the LMA may not be immediately necessary (eg, the patient may have other pressing physiologic problems, such as active hemorrhage that must be addressed) and removal of the LMA can be accomplished as soon as practical thereafter.
- Unfamiliar to many outside of the OR environment; requires use and practice for facility

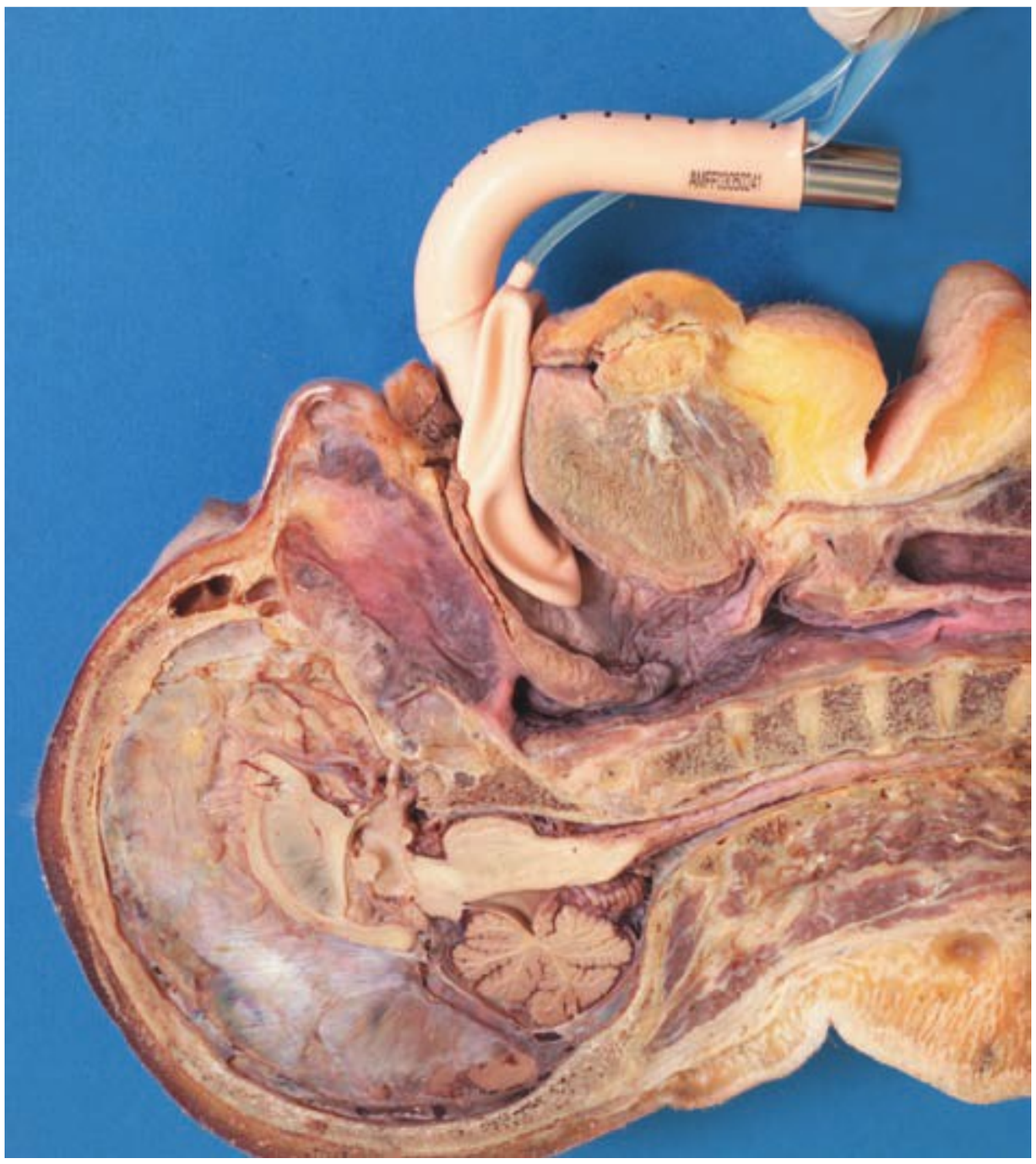


FIGURE 27-3 Placement of ILMA into pharynx of cadaver specimen.

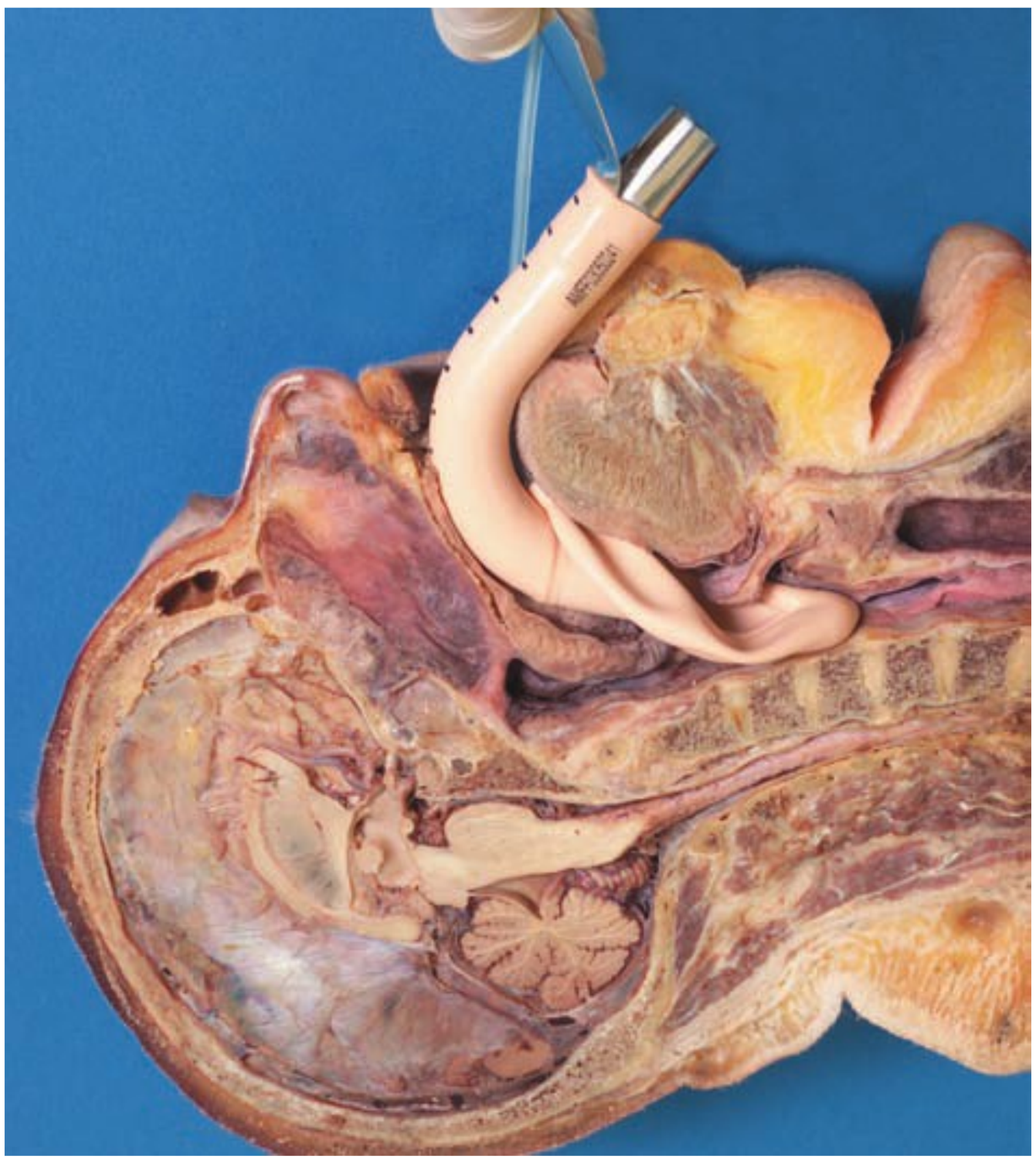


FIGURE 27-4 ILMA in place for ventilation.

FIGURE 27-5 ILMA inflated to seal glottis.

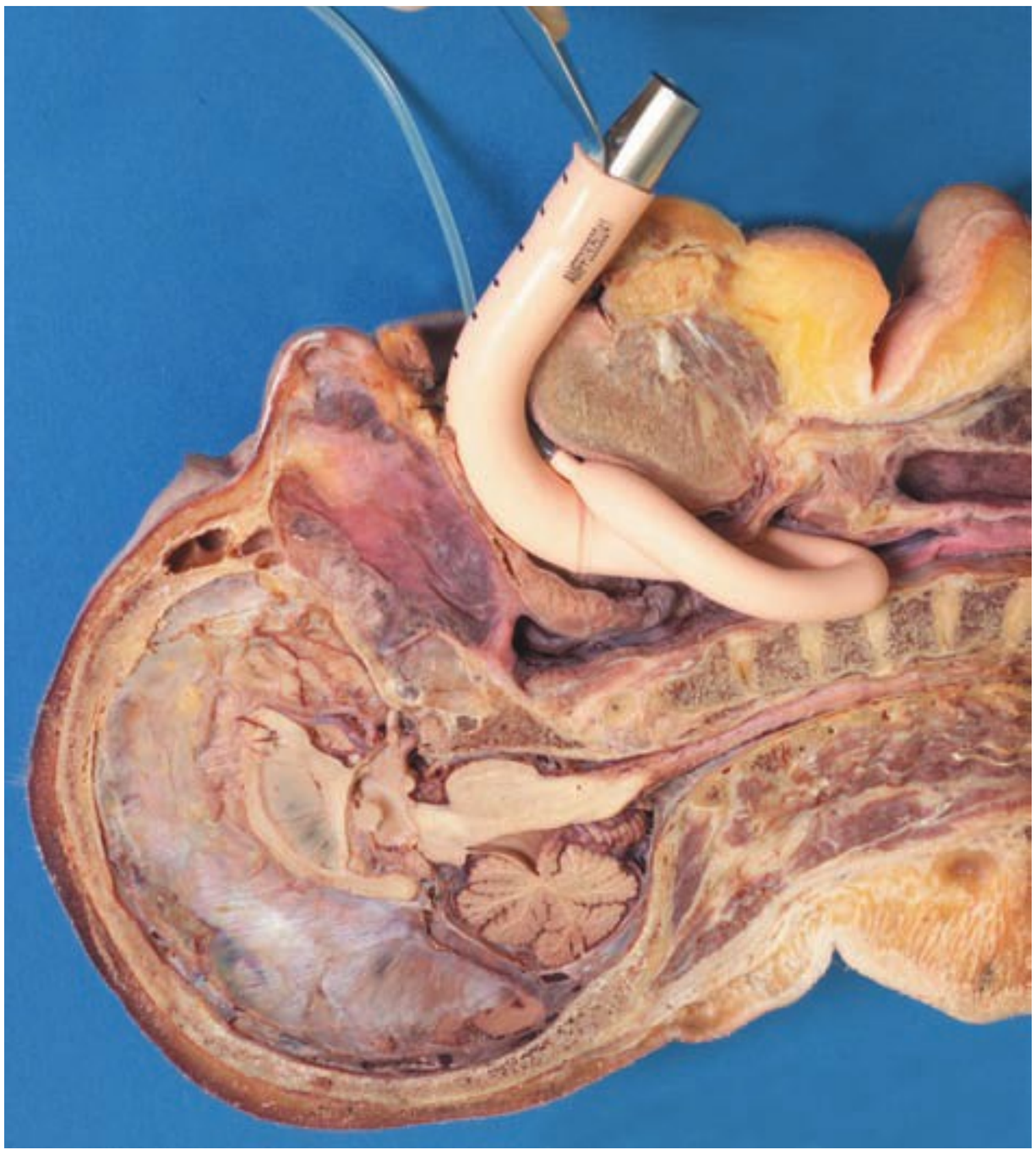
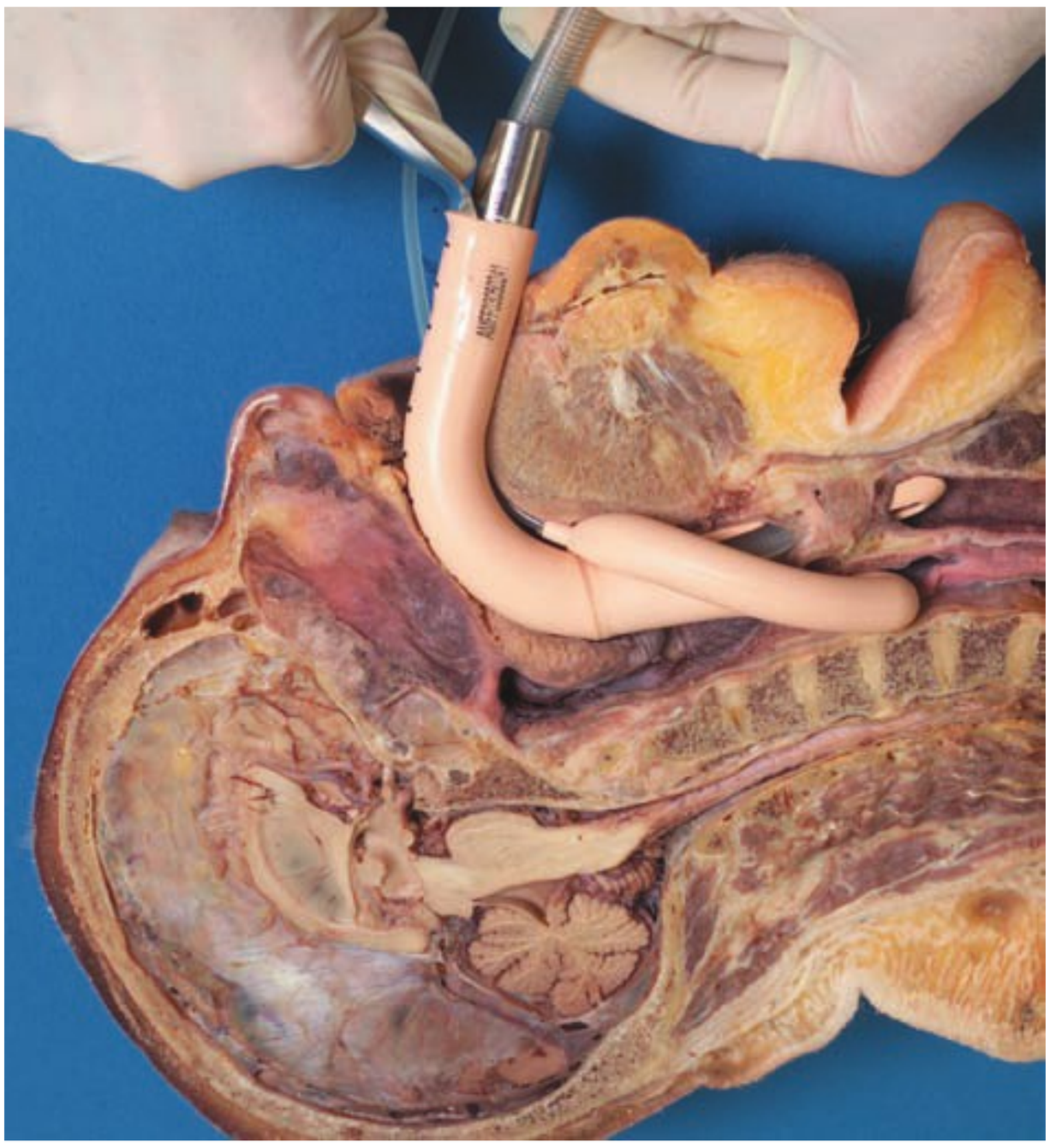


FIGURE 27-6 ETT placed through the ILMA, entering the airway.



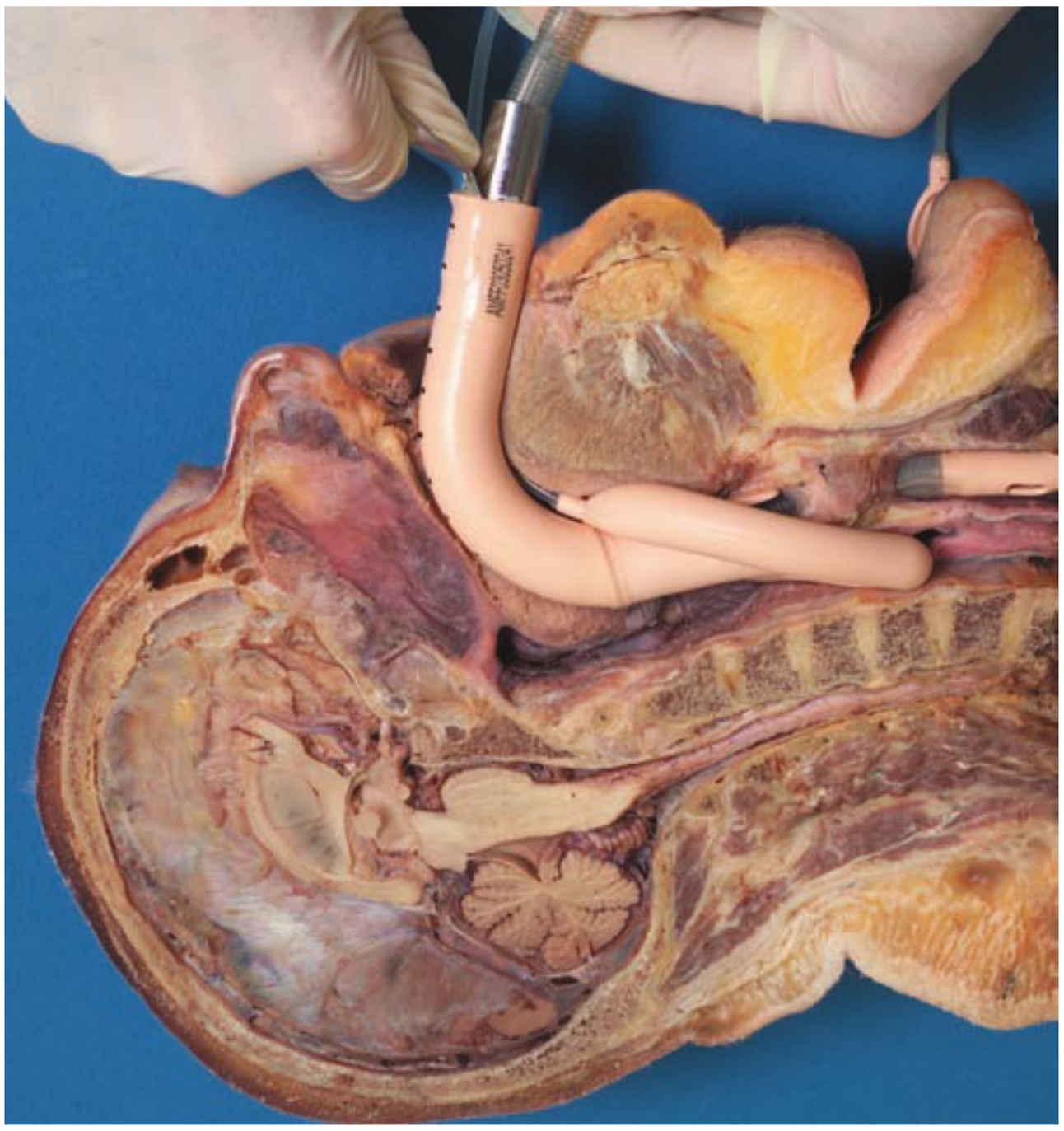


FIGURE 27-7 ETT passing into trachea.

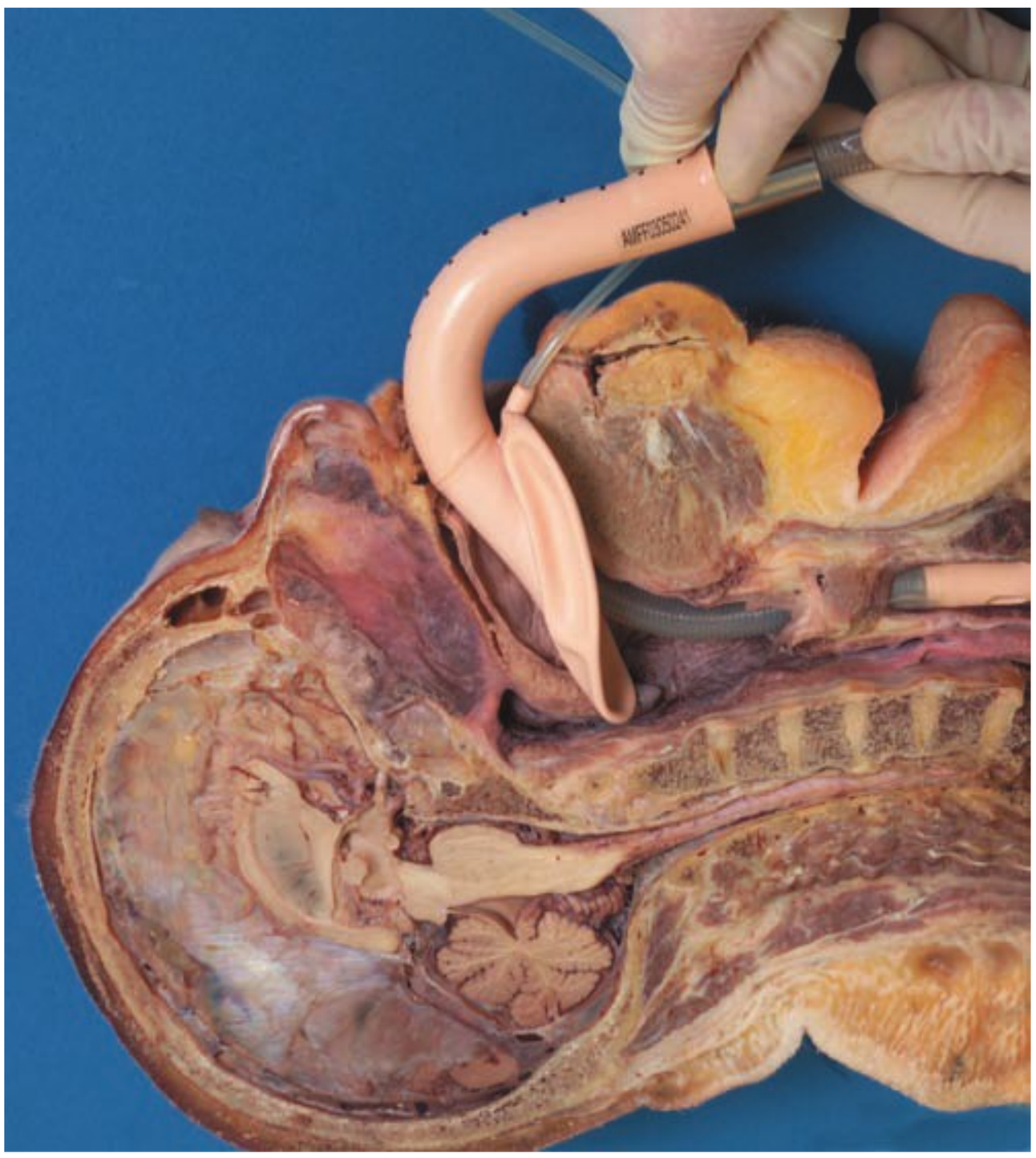


FIGURE 27-8 After the ETT is confirmed to be in the airway, the ILMA cuff is deflated and the ILMA device carefully removed. The ETT adaptor must be removed first.

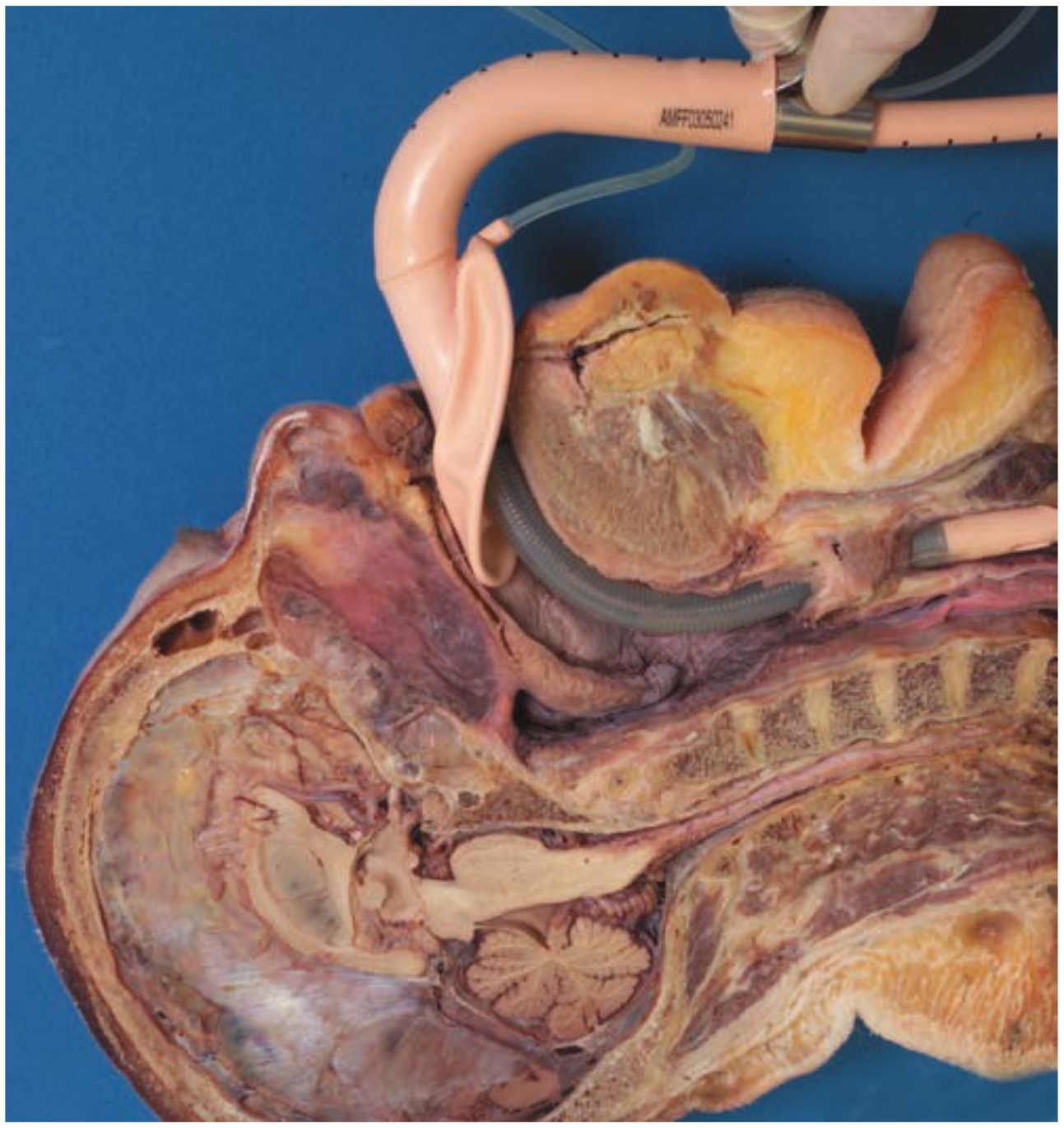


FIGURE 27-9 Use of push rod to stabilize ETT during LMA removal.



FIGURE 27-10 Grasping ETT with forceps or fingers as ILMA is extracted from mouth.

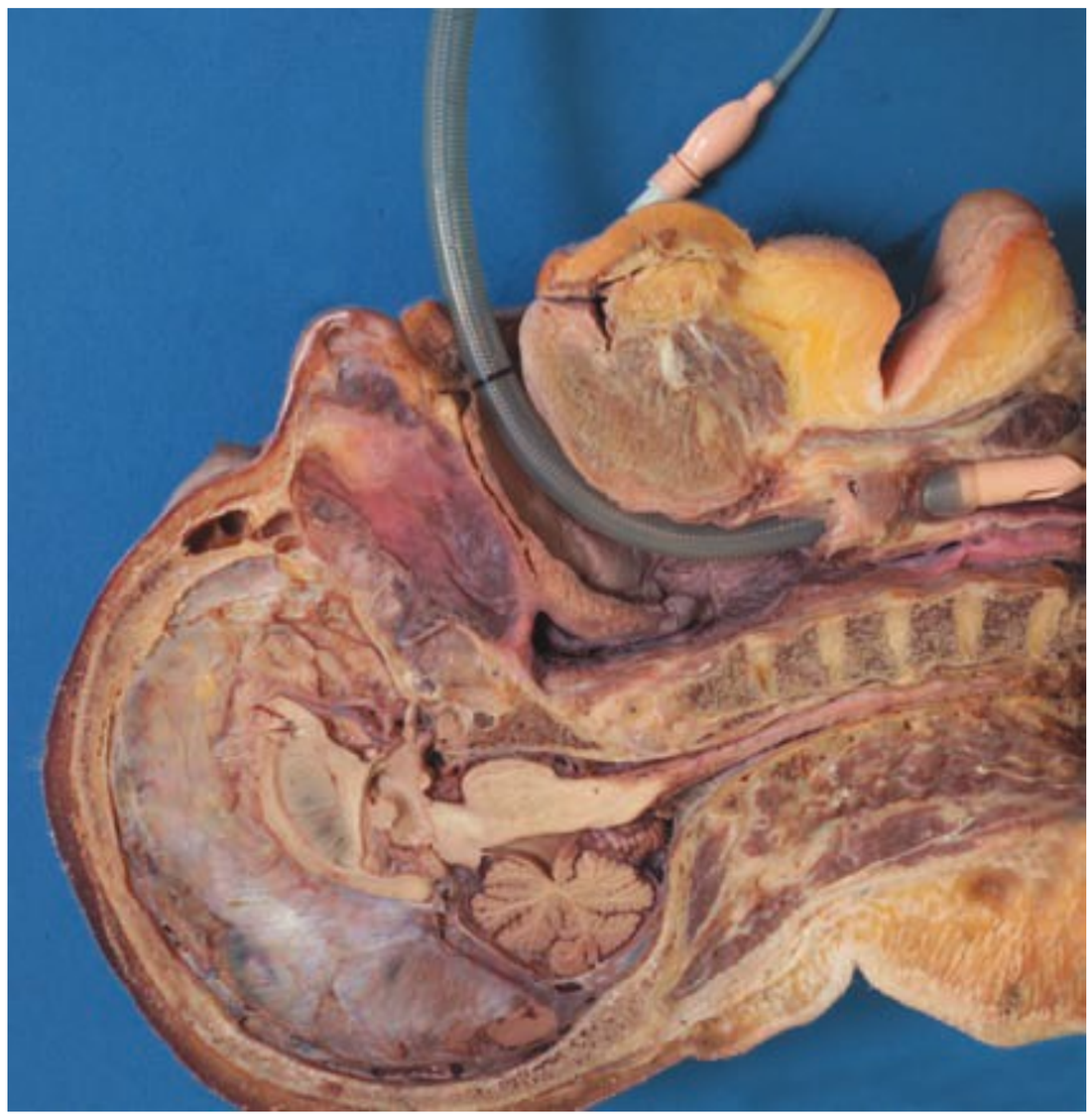


FIGURE 27-11 ETT now in place and ventilation is reinitiated and tube fixed.



FIGURE 27-12 ILMA insertion.



FIGURE 27-13 ILMA in correct position and ventilation initiated.



FIGURE 27-14 ETT insertion with black line facing cephalad. When the black band at 15 cm on the ETT reaches the lumen of the ILMA, the ETT tip is beginning to push into the pharynx, moving the EEB out of the way.



FIGURE 27-15 Adaptor attached to ETT and ventilation confirmed.



FIGURE 27-16 Use of push rod to remove LMA.



FIGURE 27-17 Grasping ETT with fingers to stabilize as ILMA is removed from mouth.

Indications

- Predicted difficult airway
- Difficult ventilation and/or intubation
- Routine airway management for elective OR cases

Contraindications

- Severe upper airway obstruction
- Inaccessibility of oral cavity

Complications

- Regurgitation/aspiration of gastric contents
- Pharyngeal trauma
- Nerve injury due to prolonged compression (if LMA is not removed)
- Failure to seal and/or ventilate with LMA
- ETT misplacement
- Inability to advance ETT

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CHAPTER 28

Other Supraglottic Airway Devices

Kristin Schreiber and Paul Bigeleisen

Concept

There are several indications for the use of a supraglottic airway device (SGA), particularly when the patient cannot be intubated or ventilated using bag-mask ventilation. In this case, successful placement of an SGA defines an emergent versus a nonemergent pathway. Although the laryngeal mask airway (LMA) and Combitube have traditionally been used in this context, the devices discussed in this chapter can also serve this purpose. Other important uses include airway management by practitioners with variable experience using direct or optically guided intubation. In the operating room, SGAs can be used in elective, spontaneous ventilation cases. In addition, some of these devices allow multiple simultaneous functions (ventilation, intubation, and gastric decompression).

One of the most important qualities when selecting an SGA is its ease of use, as it is often used in an emergent situation. Improper placement of the various SGAs is also an important consideration, as obstruction or air leak can result in difficult ventilation, ultimately increasing the risk of gastric distension and aspiration. Although supraglottic airways have a design that seeks to protect the lungs from aspiration of gastric contents or of pharyngeal secretions/blood, an endotracheal tube (ETT) has generally been considered to provide superior protection from aspiration. The results of some studies, however, suggest that aspiration occurs in 11% of cases even when ETTs are used properly.[1] In a comparison study of aspiration, episodes of hypopharyngeal pH <4 were similar in incidence between a COBRA, LMA, laryngeal tube (LT), and ETT, suggesting that the ETT may not provide superior protection against aspiration.[2] Finally, the cost and disposability of the device impacts the ability of trainees to practice and become proficient with the device.

Categorization of Supraglottic Airways

One proposed categorization scheme for supraglottic airways is based on the mechanism of sealing around the glottic aperture.[3]

1. The perilaryngeal cuffed group includes the LMA and all of its variants (reviewed in Chapter 26).
2. The pharyngeal and esophageal cuffed devices include the Combitube and LT (King).
3. The pharyngeal cuff only includes the COBRA.
4. The cuffless anatomically shaped sealers include devices such as the Streamlined Liner of the Pharyngeal Airway (SLIPA).

SPECIFIC DEVICES

Laryngeal Tube (King LT and King LTS)

Description: The LT is a blindly placed SGA containing two balloons, or cuffs, one superior, and one inferior, to the glottic opening (Fig. 28-1A, B). It is designed to fit with the distal (inferior) balloon in the esophagus, sealing this off, and the proximal (superior) balloon in the posterior pharynx, posterior to the base of the tongue and epiglottis. Inflation of 20 to 90 cc of air at a single pilot balloon fills both cuffs simultaneously, creating a seal of approximately 60 cm H_2O proximal and distal to the glottis. Positive pressure ventilation can then be achieved through multiple apertures located between these cuffs. Obstruction does not appear to be a problem with the new King LTs, which have multiple ventilation apertures[4] compared with earlier versions of the King tube. The most commonly used LT is the King LT, which was first created by VBM in Germany in 1998 and approved for use in the United States in 2003. The King LTS also has a separate lumen for suction, through which an orogastric tube can be passed. The LT is similar to the Combitube in many respects. Unlike the Combitube, however, it does not have an option of ventilating through two separate lumens.

This device is available in sizes 1 to 5:

Size	1	1.5	2	2.5	3	4	5
Weight	≤5	5–10	10–20	20–30	30–50	50–70	≥70 in kg

Evidence

Some practitioners feel that the LT is easier to insert than the Combitube and has a lower incidence of accidental laryngeal insertion because of its S shape. Additionally, its smaller size compared with the Combitube may be useful in patients with a smaller mouth opening. There have been several studies involving the LT, investigating time to and ease of placement, as well as leak pressures, in comparison with other SGAs.

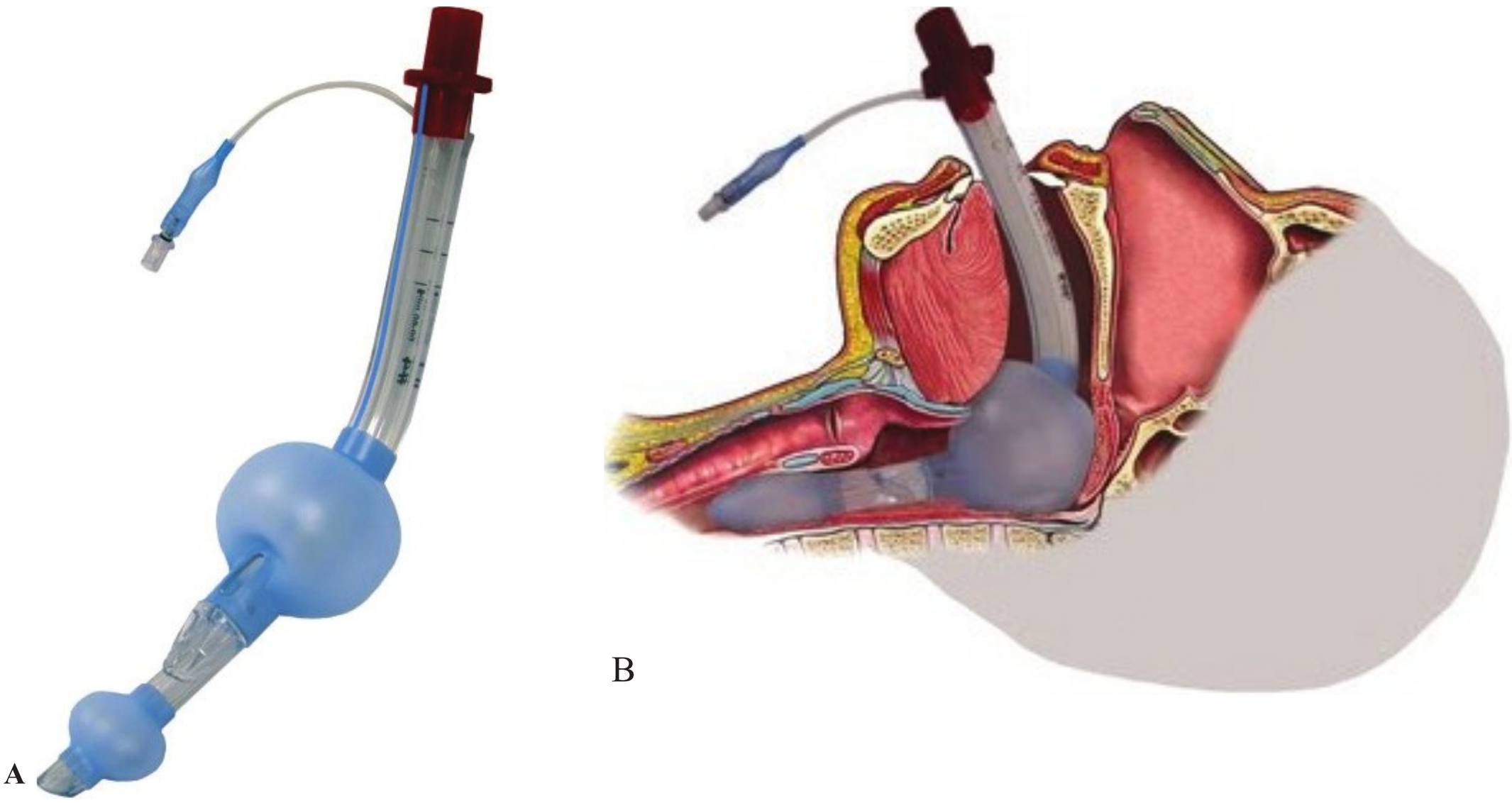


FIGURE 28-1 **A:** King LT airway. **B:** King LT airway pictured in the airway with proximal and distal cuffs inflated.

Emergency use in field: In one study investigating use of SGAs by emergency medical technicians (EMTs) during field runs in a rural setting, the LT was placed on first attempt 12/13 times, and in some of these cases after failed attempts with ETT (6/13) and Combitube (3/13).[5] In a larger study of both the King LTD and LTDS, emergency physicians and EMTs had a 98% success rate in placement. Furthermore, the time to placement in users who had 5 or less ETT insertions was: <45 seconds (n = 120), 46 to 90 seconds (n = 20), >90 (n = 7).[6] In one study, the force to dislodge various airway devices in cadavers was measured. The ETT, LMA, and King airway required similar forces, whereas the Combitube required more force.[7] This study may have relevance to patients in transport.

Use in the operating room: In a study of the King LT by experienced providers in operative cases with spontaneous ventilation, the ease of insertion was notable. The initial insertion time was <5 seconds in 98%, and 5 to 15 seconds in the remaining patients. Only 19% of these insertions required repositioning, whereas 2% required three trials at positioning. A relatively low incidence of sore throat was also described in this investigation, with 22% noted at 1 hour and 15% at 24 hours.[8] In two other studies in humans comparing the LT with the Combitube, it was revealed that faster insertion times (39 vs 79 seconds) and more successful insertion (100% vs 87%) were possible with the LT than Combitube. There was no significant gastric insufflation observed in either case, but LT had a lower seal pressure (26 vs 36 cm H_2O).[9,10] Several studies have compared the LT to LMA, and the authors found increased pressure required for leak with King LT, theoretically decreasing risk of gastric insufflation compared with the LMA.[11–13] However, in another study it was noted that there was no significant difference in leak pressures between the SGAs COBRA, LT, and LMA.[2]

Use as a difficult airway device: In another study, use of the King device was investigated in cases of failure to successfully intubate using an ETT (after three tries). Placement and use of the King airway was successful 100% of the time.[14]

Manikin/simulation studies: In some European studies using manikins, results have also suggested that the LT produces better ventilation, less gastric distention, and greater ease of insertion than the LMA or Combitube.[15–17] In several studies of prehospital emergency services staff, and medical students in a simulator setting, it has been shown that less time was required for insertion of the King LT (24.4 seconds) compared with a Combitube (37.9 seconds) and also that the practitioners expressed a preference for the King LT.[18–20] The LT has been revised in design several times throughout the years, and some of the most recent revisions have occurred since these studies.

Procedure for LT Insertion

Open the mouth with the nondominant hand, grasp the mandible and pull the mandible forward. With the LT device rotated laterally 45° to 90°, insert it behind the tongue. Advance the tube until the standard connector is just aligned with the patient's teeth. Inflate the pilot cuff to

60 cm H_2O pressure or to the minimum volume necessary to seal the airway at the peak ventilatory pressure. Attach the LTA to the breathing circuit, begin ventilation, and withdraw the LTA until ventilation is optimal. Confirm effective ventilation using auscultation, measured tidal volume, and capnometry. Readjust the cuff pressure to a volume that just seals the airway and secures the device to the patient.

Cobra Perilaryngeal Airway

Description: This SGA is essentially a breathing tube that broadens distally into the shape of the head of a Cobra snake (Fig. 28-2A, B). It has a single cuff located just proximal to this head, which, when inflated, serves to seal off the distal end from the upper airway. The slotted openings of the Cobra head hold both the soft tissue and the epiglottis away from the glottic aperture. An ETTof size 8 or smaller can be advanced through the Cobra Perilaryngeal Airway (PLA) sizes 4–6.

It is available in eight sizes and can be used for neonates as well as for infants:

Size	0.5	1	1.5	2	3	4	5	6
Weight in kg	2.5–7.5	5–15	10–35	30–50	40–100	70–130	100–160	≥160

The internal diameter of the breathing tube for adults has a range of 10.5 to 12.5 mm and all sizes can be attached to an 11 mm adapter. The cuff volume ranges from <8 mL, for neonates, to 65 to 85 mL, for small and large adults, respectively.

Evidence

Use in the operating room. There have been several studies in which the Cobra device was compared with the LMA. In one, the authors described a better airway seal with the Cobra compared with LMA.[21] In another, Schebesta et al noted leak pressures of 24 cm in the Cobra versus 20 cm in the LMA, suggesting that the Cobra provides a better airway seal than the LMA during ventilation. Conversely, there were greater detectable waste gasses at the level of the anesthesiologist in the Cobra group. In the same study, the authors found that insertion times were similar (15 seconds in Cobra vs 16 seconds in LMA). Insertion failed in 2 out of 30 in the Cobra group, but these 2 patients were also unable to be fit with LMA[22] after Cobra insertion failed. In a review of six clinical trials, the authors found mostly similar insertion times between the Cobra, LMA and LT. Half of these studies showed slightly higher leak pressures (better seal) with Cobra. However, in several of these studies it was noted that there was more frequent blood staining on the Cobra device.[23] Another study was terminated early because of two cases of aspiration.[24] Therefore, some practitioners do not to use the Cobra in cases where there is an increased risk of aspiration.

Procedure for CobraPLA Insertion

All distal portions of the device should be lubricated before insertion. After induction of general anesthesia, place the patient's head in full extension with the mouth open, and the mandible pulled upward. The package

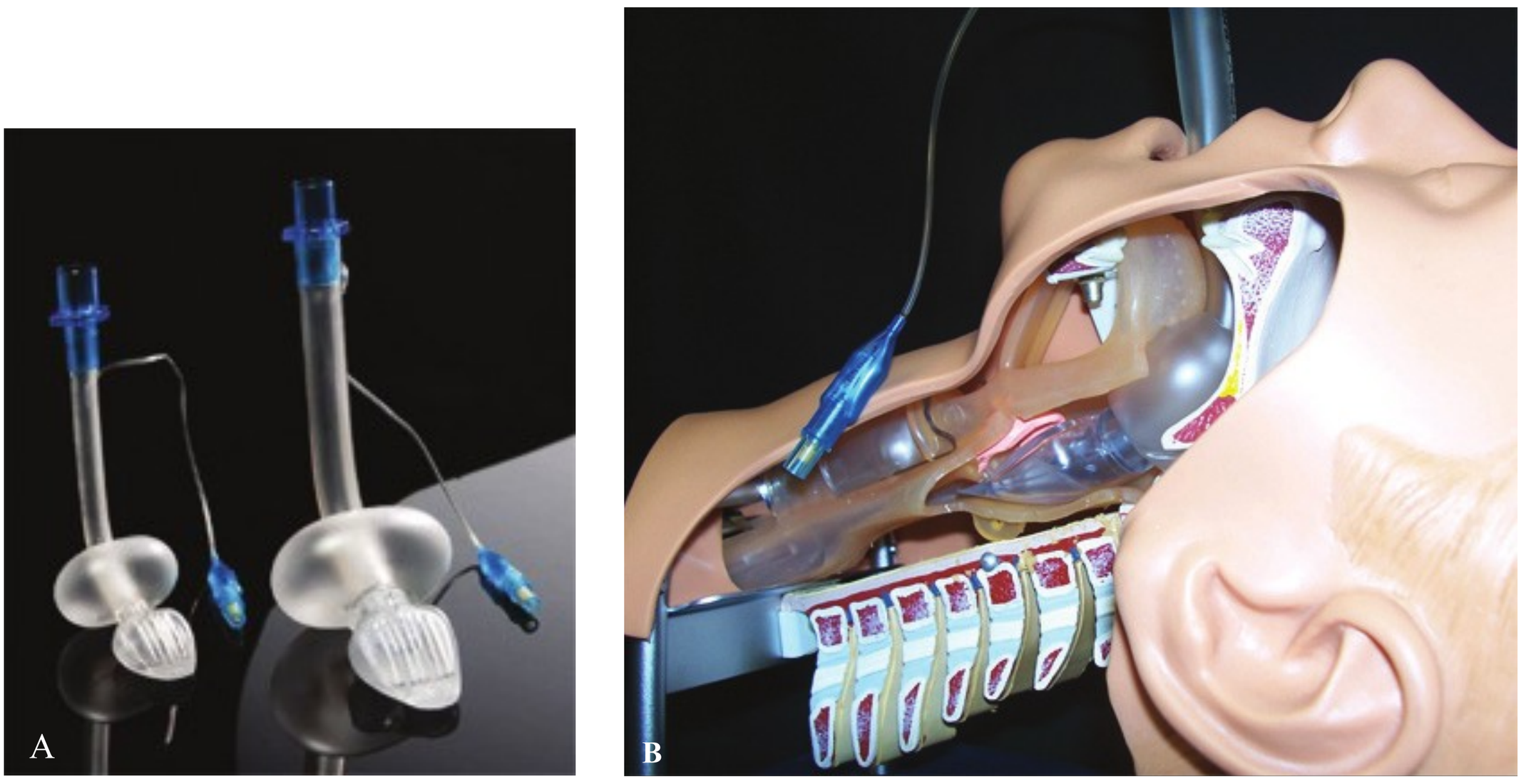


FIGURE 28-2 **A:** Cobra Perilaryngeal Airway. **B:** Cobra pictured in the airway of a manikin with inflated cuff.

insert recommends folding the fully deflated pharyngeal cuff backward away from the Cobra head to facilitate insertion. Insert the device toward the hard palate. When the tip reaches the back of the mouth, advance the device toward and past the soft tissues of the hypopharynx until moderate resistance is felt. Inflate the cuff gradually until ventilation is possible without a leak. Cuff pressure should be <25 cm H_2O. All sizes connect to a standard, 15 mm internal diameter connector. Newer versions (CobraPlus) have CO_2 sampling line and temperature probe within the device that can be directly plugged in. Prior to removal, secretions should be suctioned and the cuff completely deflated.

Streamlined Liner of the Pharyngeal Airway

Description: The SLIPA is a noncuffed, single use SGA made of latex-free soft plastic (ethylene vinyl-acetate copolymer) in the shape of a pressurized pharynx (Fig. 28-3). It is a hollow, blow-molded chamber shaped like a boot, or slipper. The body has an anterior opening that faces the patient's laryngeal inlet, through which ventilation occurs. The toe of the chamber sits in the entrance to the esophagus. The bridge in the center of the chamber with its two lateral bulges fits into the pyriform fossae at the base of the tongue, which it displaces away from the posterior pharyngeal wall. This may help to prevent the epiglottis from closing on the glottis. The heel of the chamber anchors the device in position over the soft palate and nasopharyngeal opening. It also contains a 50 mL empty internal space where pharyngeal secretions can pool, theoretically reducing the risk of pulmonary aspiration. The potential advantage of an anatomically shaped, cuffless device is that it may prevent nerve damage to the hypoglossal or recurrent laryngeal nerves from pressure effects that may occur with cuffed devices. No studies have substantiated this hypothesis.

There are seven adult sizes (47 to 57) with color-coded connectors. The number (in mm) indicates the width at the bridge. The choice of size is most easily done by a comparison with similar LMA sizing:

SLIPA size	47	49 and 51	51 and 53	55 and 57
LMA	2.5	3	4	5 Equivalent

Evidence

In one investigation, the authors noted that the SLIPA was easier to insert than LMA (94% vs 89% on first attempt) by inexperienced practitioners (medical students).[25] Conversely, in another study the practitioners found it more difficult to insert this device than the LMA, requiring a longer time (10.5 vs 7.3 seconds), with lower first time success (73% vs 93%), and blood on device in 40% of cases, versus only 6% with the LMA. There was no difference in the hemodynamic changes in patients on insertion, and once in place there was no difference in success of ventilation, leak pressures, or gastric distention.[26]

FIGURE 28-3 SLIPA.



The protection that this device offers against aspiration was studied in a simulated model of airway regurgitation, which showed that the device was able to trap aspiration contents. However, the simulated airway model was created using the SLIPA as a template. Thus, this study may not apply to clinical settings.[27]

Procedure for SLIPA Insertion

To insert the device, the patient should be under general anesthesia with his/her head in the sniffing position. The patient's mouth is opened and the device advanced toe first with the bridge side oriented toward the tongue until it reaches the entrance of the esophagus, where it seals against the cricopharyngeus sphincter. If obstruction occurs immediately after the insertion, it is likely that the epiglottis is folded down by the device. This should be corrected by extending the head and performing a jaw thrust.

If the patient emerges from general anesthesia with the SLIPA in place, a bite block may be needed to ensure continued ventilation.

Practicality

- Portable
- Inexpensive
- All three of these devices will likely be unfamiliar to those outside the operating room and will require practice on manikins or normal patients for facility in their use

Indications

- Elective airway during surgery
- Emergency ventilation when face mask ventilation fails

Contraindications

- Inaccessibility of the oral cavity
- Full stomach or aspiration risk (except in emergencies)
- Severe supraglottic obstruction

Complications

- Inability to ventilate
- Potential pharyngeal or esophageal trauma from insertion
- Regurgitation and aspiration of gastric contents
- Overinflation of cuffs, with resultant pharyngeal mucosal injury
- Injury to glossopharyngeal or superior laryngeal nerves secondary to pressure against mucosa in pharynx.

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CHAPTER 29

Transtracheal Jet Ventilation

Ana Maria Manrique-Espinel and Andrew Murray

Concept

Handheld "jet" ventilation, using high pressure to move air through small catheters, was conceived in the 1960s in an attempt to develop a device that would both maintain adequate ventilation/oxygenation and allow surgical access to the airway during endotracheal and laryngeal procedures.[1,2] Recently, this type of jet ventilation, applied via a needle placed through the cricothyroid membrane (transtracheal jet ventilation, or TTJV), is one option to restore oxygenation in the setting of an emergent difficult airway, in which neither intubation nor ventilation is possible, as recommended in the American Society of Anesthesiologists Difficult Airway Algorithm.[3] Understanding this device and its application can be life saving.

The oxygen jet stream for TTJV requires a high-pressure device. This pressure can be delivered through a supplementary pipeline, an oxygen tank with a step-down regulator, or an anesthesia machine. The working pressure that is necessary to achieve flow through a 14G catheter should be 15 psi (103 pka) at a minimum. The pipeline oxygen delivered pressure from the wall in a hospital is 55 psi. Modern anesthesia machines provide a specific connection for a handheld TTJV device, which provides adequate pressure for this device to function properly (Fig. 29-1).[4]

Manufactured TTJV devices incorporate a pressure regulator, which allows a variable pressure to be applied, and oxygen delivery is controlled with a handheld on/off valve (Fig. 29-2). Several other self-assembled devices have been adapted to connect to the handheld jet ventilator, though these are less reliable in delivery of adequate ventilation than devices designed specifically for this purpose.

The delivery of this type of jet ventilation may be performed in two ways: high frequency and low frequency. The former is typically used in intensive care units to provide very small tidal volumes for patients with poor lung compliance (see Chapter 48). Low-frequency jet ventilation through a transtracheal catheter is used in the setting of difficult airway management, when in the "emergent pathway" of the difficult airway algorithm, necessitating immediate ventilation. The handheld jet device can also be used for oxygenation during a bronchoscopy or a rigid laryngoscopy procedure (see Chapter 43). The typical frequency of ventilation in such settings is 8 to 10 breaths per minute, allowing enough time for exhalation, and decreasing the risk of air-trapping and barotrauma. Exhalation should be confirmed by observing chest motion before a subsequent tidal volume is delivered.

With TTJV, the FiO_2 delivered is lower than 100%, because ambient air is entrained with each pulse of high-pressure gas. Alveolar ventilation is dependent on the ventilatory rate and the effective tidal volume. Delivered gas flow during ventilation is typically in the range of 0.5 to 1 L per second, depending upon catheter size. Because there is a risk of increased intrathoracic pressure with every inhalation, the inspiratory time should be limited to 0.5 or 1 second. A pause between insufflations is performed, allowing passive exit of the air secondary to the recoil of the chest wall (an inspiratory to expiratory ratio of 1:3 or 1:4 is appropriate). This methodology assumes a normal lung compliance (50 mL/cm H_20), with a pressure delivery system not higher than 50 psi. However, in a lung with reduced compliance, more careful delivery of the insufflations should be performed, with an eye toward avoiding dangerously high inspiratory pressures.

There are several types of catheters available to perform needle cricothyroidotomy for TTJV. Fourteen-gauge or sixteen-gauge intravenous-type catheters are commonly used, and commercial devices are available as well, some with reinforcement to prevent kinking (Fig. 29-3). The VBM Manujet III (VBM medical, Noblesville, IN, USA) package includes the handheld jet ventilation device, a jet injector and teflon catheters, in sizes 13G, 14G, and 16G, for infants and adults. These catheters have a Luer lock to facilitate connection to the handheld jet ventilator. In addition, the distal parts of these catheters have lateral holes to decrease the venturi effect and to maintain the catheters far from the tracheal wall.[5]

Evidence

TTJV was demonstrated to provide adequate ventilation in cardiac arrest patients as early as 1972, when Jacobs described its use in 40 cases.[6] While using a high-pressure oxygen source, the author was able to maintain an average PaO_2 of 300 mm Hg, and a $PaCO_2$ of 22 mm Hg with peak airway pressures of 15 to 25 cm H_2O. In 1975, Smith[7]

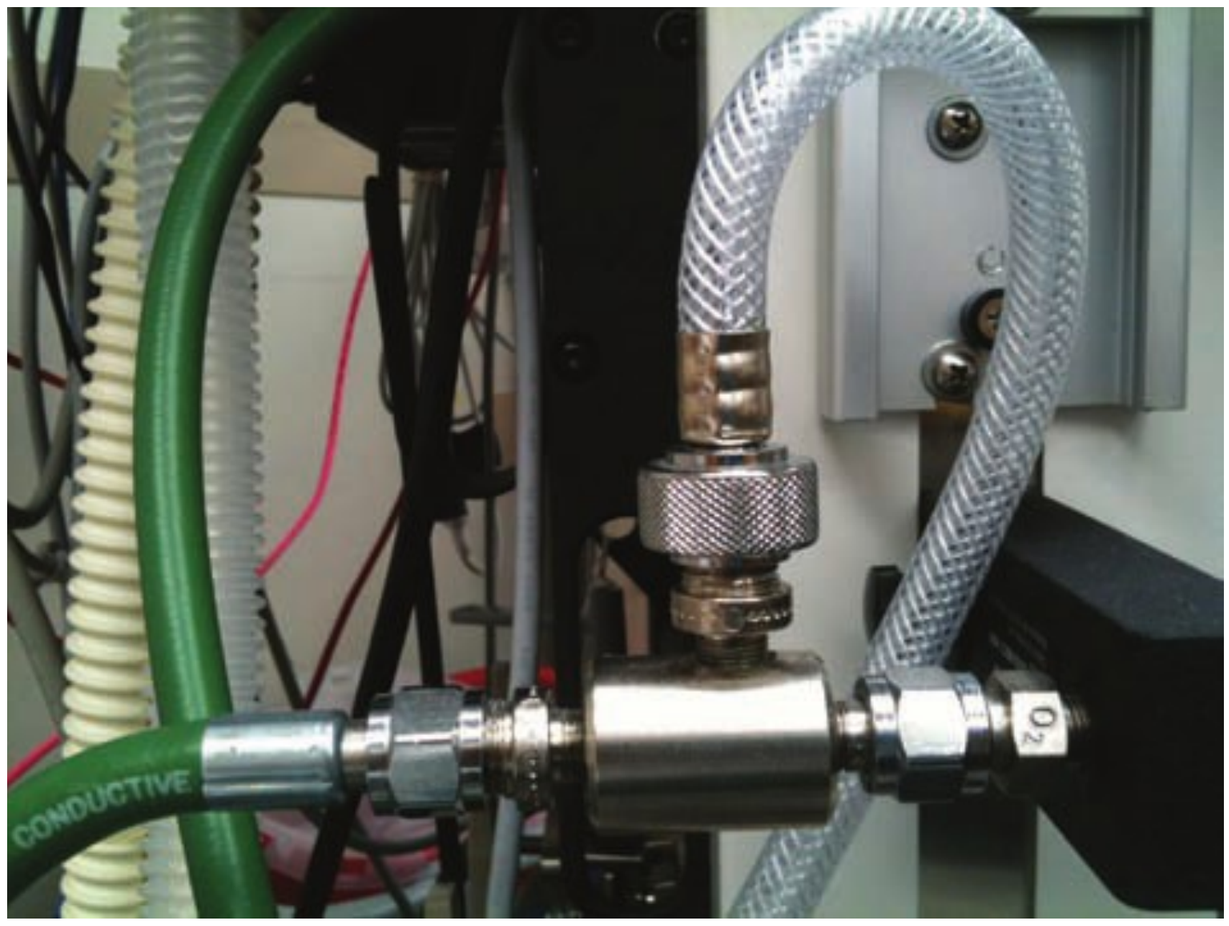


FIGURE 29-1 Anesthesia machine adaptor for JET ventilator.



FIGURE 29-2 Regulator of pressure and hand valve on–off of the JET ventilator.



FIGURE 29-3 Transtracheal needle.

described the use of TTJV in 80 patients who underwent airway surgery under general anesthesia. Fifty-two of these cases involved elective use of the technique, whereas 28 of the patients were managed while in respiratory distress. Several case series have shown the benefit of this technique in patients with significant airway disease and severe glottic narrowing, in whom tracheostomy would be difficult.[8] Provided that adequate pressures are used to provide necessary flow rates, several investigators have demonstrated that normocarbia can be maintained while ventilating patients with TTJV.[9,10] Many of the patients described in these investigations were under general anesthesia, in contrast to patients in acute respiratory failure who are frequently encountered in the hospital wards, intensive care units, or emergency department. TTJV also has been useful in high-grade upper airway obstruction, as in the case of a patient with a large carcinoma at the base of the tongue who sustained a respiratory arrest.[11] TTJV has been used effectively as a ventilation strategy in cannot intubate, cannot ventilate (failed airway) situations.[12–14] The technique has also proven useful in pediatric airway emergencies.[15]

Preparation for TTJV Using a Commercially Available Device

- Preparation for direct laryngoscopy (see Chapter 5)
- Anesthetized or unconscious, preoxygenated patient with head extension to allow access to cricothyroid membrane
- Attach the high-pressure tubing of the device to 50 psi wall oxygen source (or oxygen tank with two-stage regulator)
- Check integrity of components, test oxygen flow
- Prepare the neck over the cricothyroid membrane with antiseptic solution, if time allows

Procedure (Figs. 29-4–29-10)

- First, the cricothyroid membrane should be identified (Figs. 29-4 and 29-5).
- An angiocath needle is attached to a 10 ml syringe filled with 5 ml of normal saline. A 14 or 16 gauge angiocath needle (or a similar sized commercial device for cricothyroid puncture) is attached to a 10 ml syringe filled with 5 ml of normal saline.
- The needle is advanced in a 30 degree angle to the long axis of the trachea with the tip directed caudal, continuously aspirating until the free aspiration of air is detected. Note that the commercial needle depicted is curved, so that the tip is pointing caudad into the distal airway (Fig. 29-6)
- The angiocath is advanced over the needle in a caudad direction. The hub should be held firmly at all times until the Luer hub is connected with the jet ventilator. Air should be aspirated from the catheter after needle removal to ensure it is within the lumen of the airway (Fig. 29-7)
- Ventilation can then be delivered via the handheld device. The inspiratory time should typically be between 0.5 and 1 second (until chest rise is just appreciated) and the inspiratory:expiratory ratio is between 1:3 and 1:4 (Fig. 29-8)
- Care should be taken that one person is always tasked with making sure that the catheter is stabilized at the skin to prevent any catheter migration with possible ill-effect (Fig. 29-9)



FIGURE 29-4 Palpating the cricothyroid membrane between the marked thyroid and cricoid cartilages.



FIGURE 29-5 Cricothyroid membrane demonstrated in cadaver specimen.



FIGURE 29-6 Puncture of cricothyroid membrane.



FIGURE 29-7 Attach syringe to catheter, pull back bubbles to reconfirm position in airway.

- Another important point during the TTJV is to maintain the supraglotic area open to permit free exhalation of gas and avoid air trapping. In this regard, an oral or nasal airway device (or both) can be used (Figs. 29-8 and 29-9)
- After this procedure, a definitive airway should be established, such as a tracheostomy. Occasionally, the view of the glottis during direct laryngoscopy is improved during TTJV, due to the high airway pressures. In addition, fiberoptic bronchoscopic intubation may be facilitated by TTJV (see Chapter 35).

Practicality

- Reasonably inexpensive: ($200 to $300 for available system)
- Commercial systems are portable and simple



FIGURE 29-8 Attach TTJV system with Luer lock, begin ventilation. Oral and nasal airways should be in place to ensure exhalation is unimpeded, or barotrauma may occur.



FIGURE 29-9 An assistant should now be designated to hold the hub of the catheter until a definitive airway is established.



FIGURE 29-10 If the needle is advanced too far during puncture of the cricothyroid membrane, perforation of the esophagus may occur.

- Unfamiliar: user should practice hooking up components and identifying and instrumenting cricothyroid membrane
- Difficult anatomy prohibiting the identification of the cricothyroid membrane

Indications

- Failed intubation and/or failed ventilation
- Inaccessibility to oral cavity in patient requiring emergent ventilation
- Severe facial trauma with inaccessible airway
- Severe upper airway obstruction precluding other, supraglottic, emergent ventilation techniques, or failure of these techniques

Contraindications

- Bleeding diathesis
- Severe supraglottic obstruction

Complications

- Subcutaneous emphysema
- Pneumothorax
- Pneumomediastinum[16]
- Pneumoperitoneum
- Dysrhythmias and gastric distension
- Catheter displacement or kinking
- Laryngeal or esophageal perforation (Fig. 29-10)[17]
- Hemodynamic changes may occur with air-trapping or high peak inspiratory pressures, resulting in decreased cardiac filling, hypotension, and cardiovascular collapse

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PART IX

Combination Techniques

CHAPTER 30

Intubation through Laryngeal Mask Airway or Intubation Laryngeal Mask Airway with a Bougie, Lighted Stylet, or Optical Stylet

Steven L. Orebaugh

Concept

As noted in previous chapters, both the laryngeal mask airway (LMA) and the intubating laryngeal mask airway (ILMA) are optimally positioned when lying in the hypopharynx, with the mask atop the glottic opening. This position facilitates passage of a guiding catheter through the tube of the device, often directly into the glottis. An endotracheal tube (ETT) can then be passed over it and into the trachea. The LMA lumen limits the size of the ETT to be passed to a size 6.0-mm internal diameter (ID) in a size 3 or 4 LMA, or a 7.0-mm ID in a size 5 LMA. The 6.0 ETT can project only a short distance past the mask of the LMA, into the larynx, due to the length of these tubes when compared with the length of the LMA itself. In contrast, the ILMA device, in all three sizes, has a lumen large enough to accommodate size 8.0 ETTs. Furthermore, the design of the ILMA and the push rod included with it facilitate removal of the device after the ETT is seated and confirmed to be in the airway.

Evidence

Anecdotal reports exist that describe the placement of a bougie through an LMA to improve the potential for accurate intubation.[1] However, this technique is probably no better than simply inserting an ETT through the LMA, without guidance,[2] which has a high failure rate.[3] These blind techniques are less successful than those that allow visualization of the airway. In a comparison of intubation through the LMA with the use of a bougie versus the ILMA combined with the use of a fiberscope for direct visualization, in patients with in-line cervical immobilization, Asai[4] reported a success rate of 85% for the latter combination but less than 50% for the former.

A technique that has generated more interest, and is likely to improve the accuracy of ETT placement, is the use of a lightwand, placed through an LMA or ILMA device, to allow the practitioner to guide an ETT into the larynx with transillumination. Agro et al made use of this technique in 114 patients under anesthesia, after LMA insertion. After successful LMA placement, the lightwand and ETT were inserted into the LMA, projecting 1.5 cm beyond the grill.[5] In 78% of patients, the authors were able to intubate without repositioning the LMA, whereas 10% required repositioning, and 9% required a change to different-sized LMA. Three patients were impossible to intubate in this manner.

Nijima et al[6] reported use of the Trachlite (Laerdahl, Long Beach, CA, USA) lightwand with the intubating LMA. In their approach, the stiff internal stylet of the lightwand is withdrawn, and the device is threaded through the Murphy eye of the ETT, then its tip placed through the ILMA lumen. With gentle insertion of the lightwand, probing for the glottis, transillumination was used to guide the ETT into the larynx. Dimitriou et al evaluated the ILMA as an effective intubating device using a flexible lightwand in unexpected failed laryngoscopy in 11,621 patients. The study participants could not intubate a total of 44 patients with direct laryngoscopy in three attempts.[7] Ventilation with the ILMA was accomplished in all of these 44 patients; lightwand-guided intubation through the ILMA was successful in 86% on the first attempt, 12% on one or more subsequent attempts, and failed in one patient (2%). An optical stylet has also been used for intubation through the ILMA.[8]

Preparation for Lightwand-assisted Intubation through the LMA

- Same as for LMA insertion (see Chapter 26)
- Lubricate lightwand and ETT
- Place lightwand through ETT, with tip flush with end of tube
- Anesthetized or unconscious, preoxygenated patient in neutral position

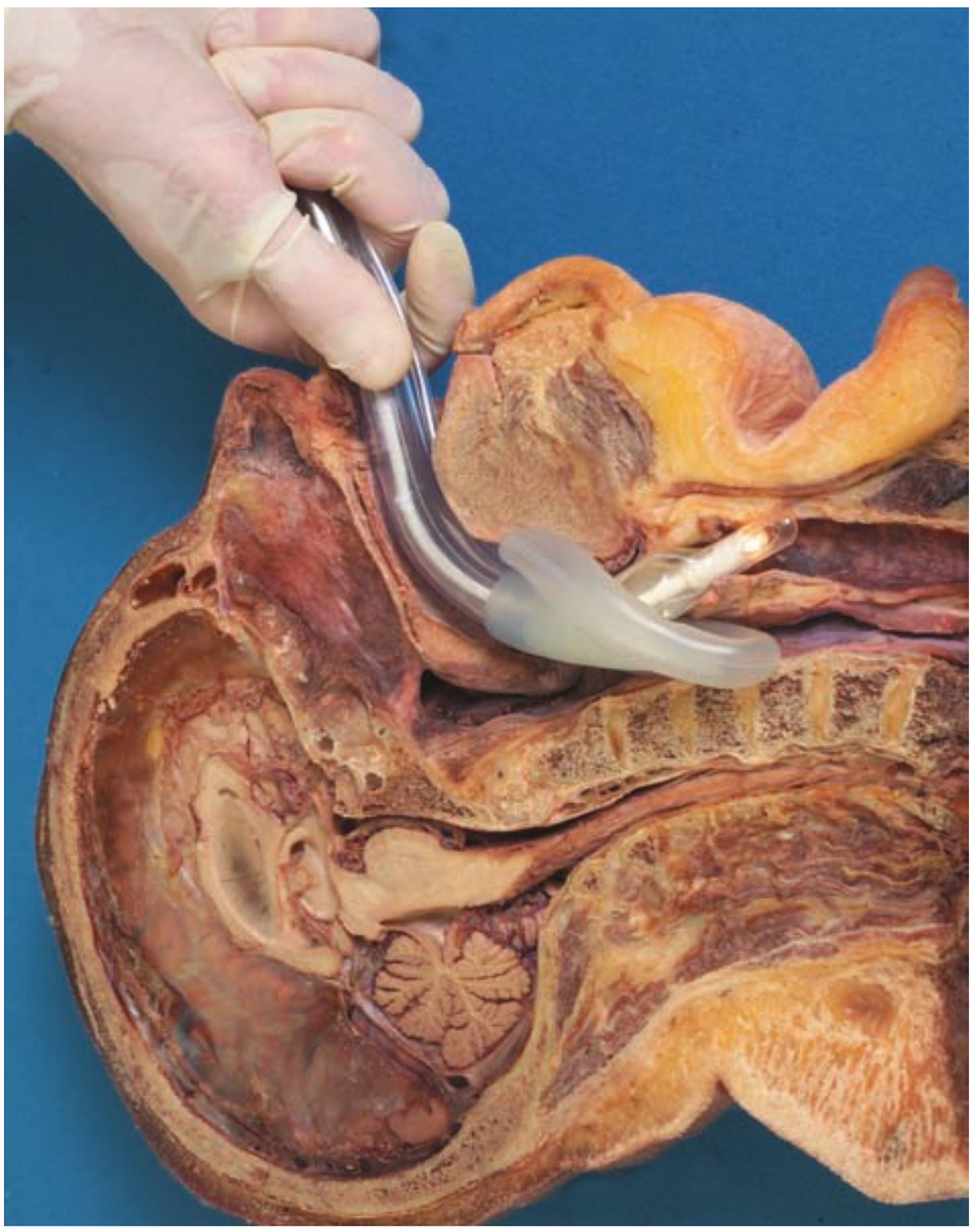
Procedure for Lightwand-guided Intubation through LMA (Figs. 30-1–30-3)

- Insert LMA (see Chapter 26)
- Establish optimal ventilation pattern
- Insert lightwand/ETT through lumen of LMA, to project 1.5 cm from the grill of the distal LMA lumen
- Alternatively, insert ILMA and establish optimal ventilation, then place ETT/lightwand through lumen
- Observe neck for transillumination
- Advance lightwand when transillumination indicates glottic entry
- If halo of light not seen over the crycothyroid membrane (CTM), the LMA should be repositioned, depending on the location of visible light, by advancing, withdrawing, or rotating it, or by placing a different size LMA (or ILMA)
- Advance lightwand/ETT until halo passes beyond CTM to suprasternal notch
- Advance ETT and remove lightwand
- Ventilate through ETT, confirm placement in airway
- Leave LMA device in place with deflated cuff (or, if using ILMA, remove it with push rod)
- Fix ETT/LMA in place

Practicality

- Simple, portable, affordable
- Unfamiliar: requires practice to fit lightwand/LMA through device and familiarity with transillumination of the larynx

FIGURE 30-1 Insertion of ETT/lightwand into LMA situated in cadaver specimen.



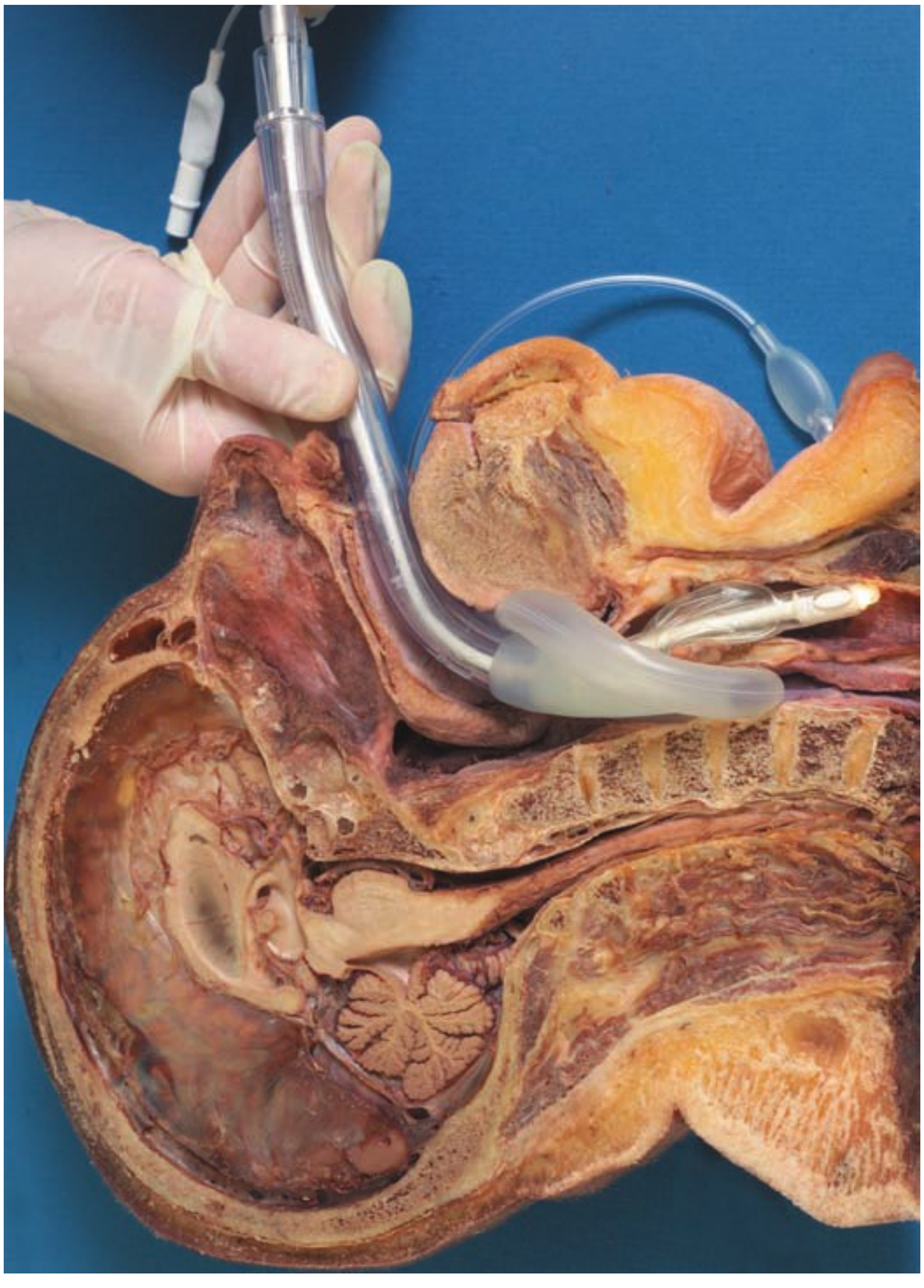


FIGURE 30-2 Lightwand/ETT advanced into airway. Note that only a few centimeters of the 6.0 cm ETT enters the larynx when inserted through the LMA.

Indications

- Inability to intubate trachea by direct laryngoscopy
- Copious blood or secretions in airway (precluding techniques that require glottic visualization)
- Necessity of ETT after emergency ventilation with LMA

Contraindications

- Laryngeal fracture or trauma
- Inability to ventilate through LMA
- Upper airway obstruction

Complications

- ETT misplacement in esophagus
- Inability to advance lightwand/ETT
- Laryngeal or pharyngeal trauma from blind probing

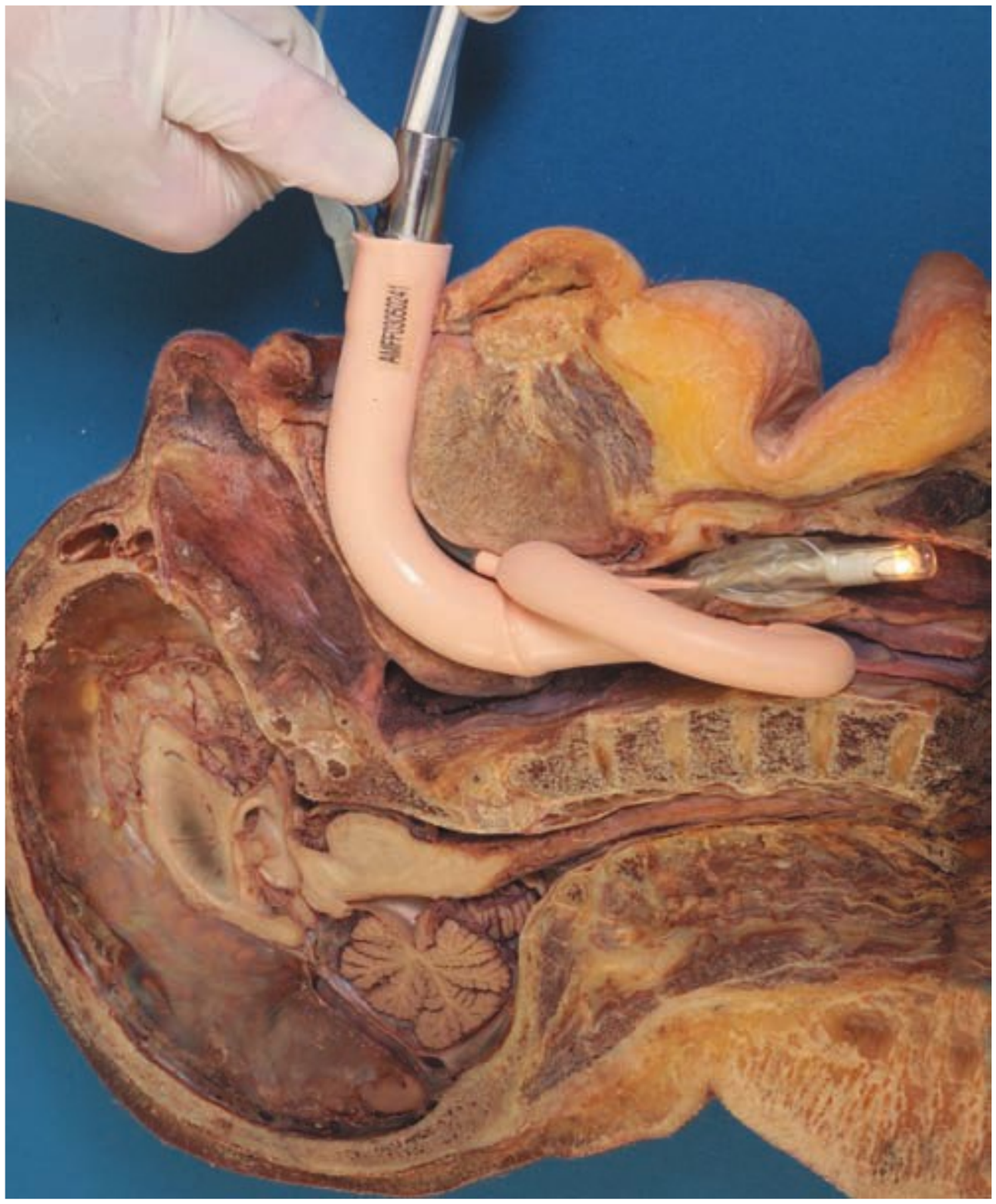


FIGURE 30-3 A larger ETT may be inserted, and to a greater depth in the larynx, when the ILMA is used with the lightwand.

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CHAPTER 31

Retrograde Intubation and Flexible Fiberoptic Bronchoscope Intubation

Steven L. Orebaugh

Concept

Retrograde intubation (RI) was discussed in Chapter 22. Although reported success rates are high, RI remains a "blind" procedure: the endotracheal tube (ETT) is advanced with wire guidance, and there is no visualization of the glottis as the tube is moved forward. The ETT may move out of the larynx, into the esophagus, or kink, with failure to advance, after the wire and guide catheters are removed. To improve the success of RI, it can be combined with a fiberoptic bronchoscope (FOB) in order to obtain direct visualization of the airway as the tube is advanced and immediately confirm appropriate placement of the ETT.[1,2] When the guidewire is retrieved from the mouth, it is fed through the working channel of the FOB from distal to proximal. The FOB is then fed over the wire to the glottis. After the wire is removed, the FOB acts as a visualizing guide catheter. This reduces the chance that the ETT will be dislodged from the trachea during the blind technique, as the glottis can be visualized throughout.

Evidence

Case reports attest to the use of this combination of airway management techniques.[1–3]

Preparation

- Same as for RI (see Chapter 22)
- Same as for fiberoptic bronchoscopy, except that this combination would most likely be used in an unconscious patient, so that topicalization is unlikely to be necessary (see Chapter 23)
- Remove the rubber or plastic cover from the suction port of the FOB, to allow wire to emerge from the suction channel

Procedure (Figs. 31-1–31-5)

- Carry out RI steps 1 through 5. No guide catheter is used
- Retrieve wire from mouth, thread into suction channel at tip of the FOB, until it emerges from suction port
- Pull end of wire out of proximal end of FOB, clamping it or having assistant hold it throughout the ETT insertion
- Maintain tension on wire and insert FOB along it (using wire as a guide to FOB advancement)
- Jaw thrust and/or direct laryngoscopy will likely be required
- Visualize larynx, advance FOB through it, to point of wire entry into larynx
- Advance FOB into trachea, if possible (if FOB will not advance past glottis due to wire, wire can be cut and removed to allow scope to pass)
- Carefully remove guidewire without dislodging FOB from larynx
- Advance FOB to within sight of carina
- Slide ETT over FOB, confirm position, remove FOB
- Fix ETT in place

Practicality

- Complex, unfamiliar: requires practice
- Expensive due to use of FOB
- Not easily portable, due to FOB
- All of the logistics issues of FOB apply (see Chapter 23)

Indications

- Difficult airway predicted
- Inability to intubate, with preserved ability to ventilate

Contraindications

- Copious secretions/blood in airway
- Inability to ventilate, due to time required for this procedure
- Distorted, traumatized, or unrecognizable laryngeal anatomy

Complications

- Complications of both RI and FOB intubation are possible with this combined technique (see Chapters 22 and 23)

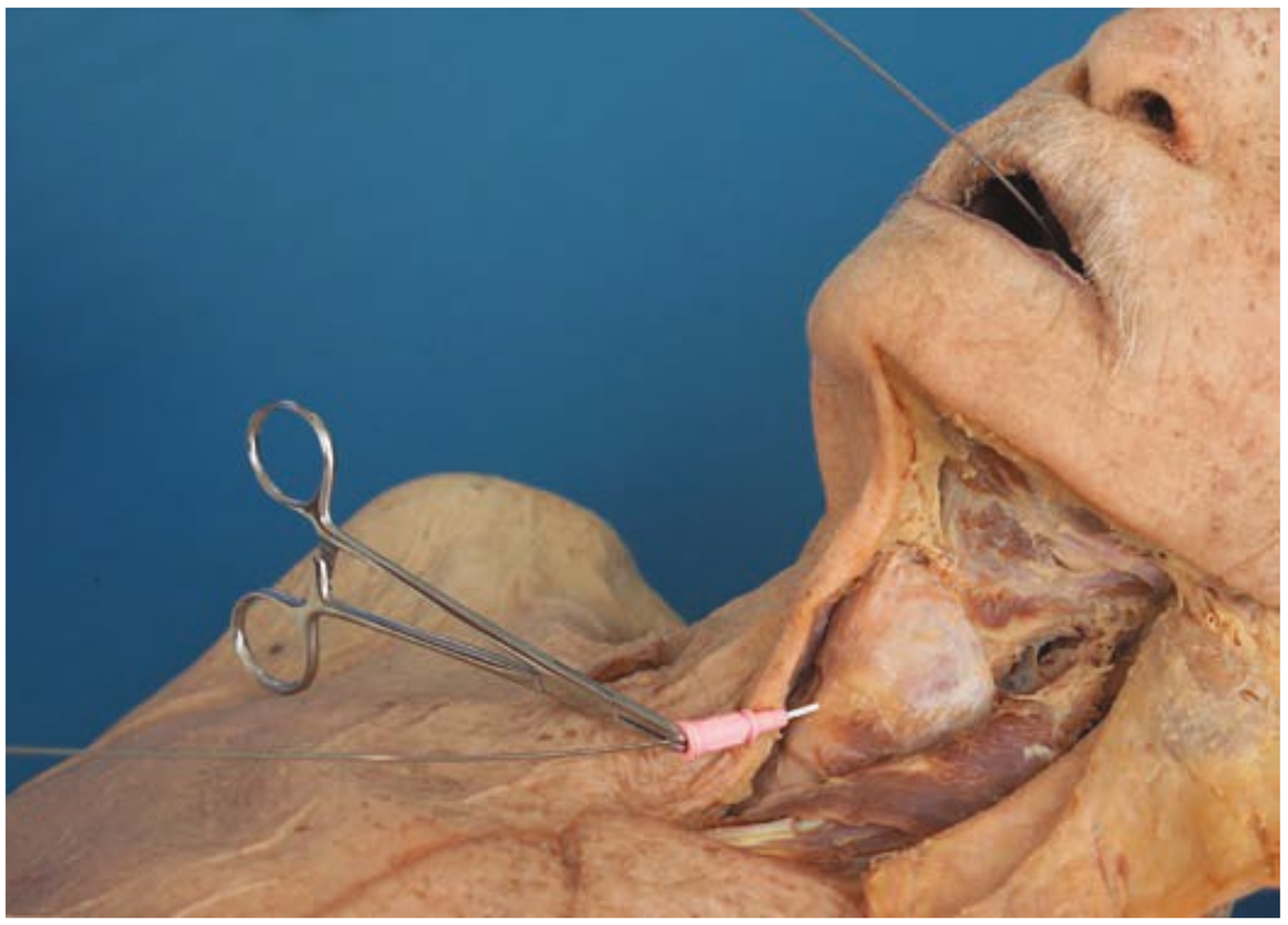


FIGURE 31-1 Wire has been retrieved from the mouth during RI in cadaver specimen.



FIGURE 31-2 RI wire is now inserted into suction channel of FOB.



FIGURE 31-3 FOB is advanced over the wire, while maintaining tension on wire.



FIGURE 31-4 When the tip of the FOB abuts the CTM, the wire is removed from either the CTM or the suction port of the scope.



FIGURE 31-5 After the wire is removed, advance the FOB distally in the trachea until the carina is visualized. Then advance the ETT as in any FOB-guided intubation.

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3. Tobias R. Increased success with retrograde guide for endotracheal intubation. *Anesth Analg*. 1983;62:366–367.

CHAPTER 32

Flexible Fiberoptic Bronchoscope Intubation through the Laryngeal Mask Airway

Steven L. Orebaugh

Concept

One aspect of intubation with a fiberoptic bronchoscope (FOB) that can be frustrating is the tendency to advance the scope into the pharynx off of the midline, failing to view the glottis and becoming "lost" in the pharyngeal mucosa. The laryngeal mask airway (LMA) provides an excellent introducer for the FOB because it is usually positioned directly atop the glottis, and whether the epiglottis is held open or folded down, it facilitates passage of the tip of the scope into the airway.[1] The size 4 LMA, in both reusable and disposable versions, can only admit a size 6.0-mm internal diameter (ID) or (at best) size 6.5-mm ID. Although such a tube is adequate in diameter for ventilation of most adults, its length is foreshortened compared with larger diameter endotracheal tubes (ETTs), and it reaches only about 1 to 2 cm past the vocal cords and into the larynx when passed through the LMA device. Therefore, long-term stability of this ETT may be an issue, as even minor movement of the head or neck may dislodge it. Furthermore, it is difficult to remove the LMA without dislodging the ETT. However, for short-term use, as in the operating room, or for emergency ventilation followed by intubation during difficult airway management in other settings, the use of the LMA to assist with FOB intubation is a valuable technique.

Evidence

Several case reports support the value of using FOB to intubate through the LMA.[1–4]

Preparation

- Prepare for LMA insertion (see Chapter 26)
- Prepare for FOB intubation, using a 4-mm scope (larger scopes will be difficult to insert through the 6.0 or 6.5-mm ID ETT) (see Chapter 23)
- If difficult ventilation requires emergent LMA insertion, then the ETT/FOB can be inserted through it during ongoing ventilation, using an FOB adaptor in the circuit: the tight fit of the ETT in LMA lumen allows ventilation through the ETT during insertion
- Anesthetized, preoxygenated patient in neutral or sniffing position

Procedure (Figs. 32-1–32-6)

- Insert LMA (see Chapter 26)
- Confirm adequate ventilation through LMA
- After FOB is prepared, insert its tip into the proximal end of the LMA
- An FOB elbow adaptor can be attached to the 15-mm adaptor of the ETT, and the ETT advanced through the LMA to its grill; attaching a breathing circuit to the FOB adaptor will then allow ongoing ventilation during FOB intubation attempts
- Advance FOB through LMA, and visualize glottis beyond the grill at the end of the LMA lumen
- Push scope tip through LMA grill, enter glottis, and advance until carina is visualized
- Advance ETT over FOB until its adaptor is flush against the adaptor of the LMA
- Remove FOB
- Confirm breath sounds, $ETCO_2$, and tube position
- Deflate cuff of LMA but do not attempt to remove
- Secure ETT/LMA in place
- If long-term intubation is required, efforts should be made to place a longer ETT into the trachea for improved airway security (using FOB or tube changer device)

Practicality

- Expensive due to incorporation of FOB
- Neither simple nor familiar: requires training and practice
- Portability compromised due to FOB
- All of the logistics issues of FOB apply (see Chapter 23)

Indications

- Difficult ventilation (LMA used initially as a lifesaving ventilation technique, followed by FOB intubation)
- Difficult intubation (LMA used as a guidance device for FOB)

Contraindications

- Copious blood or secretions in airway
- Inaccessibility of oral cavity (unable to insert LMA)
- Severe upper airway obstruction

Complications

- Complications of both LMA insertion and FOB intubation are possible with this combination technique (see Chapters 23 and 26)

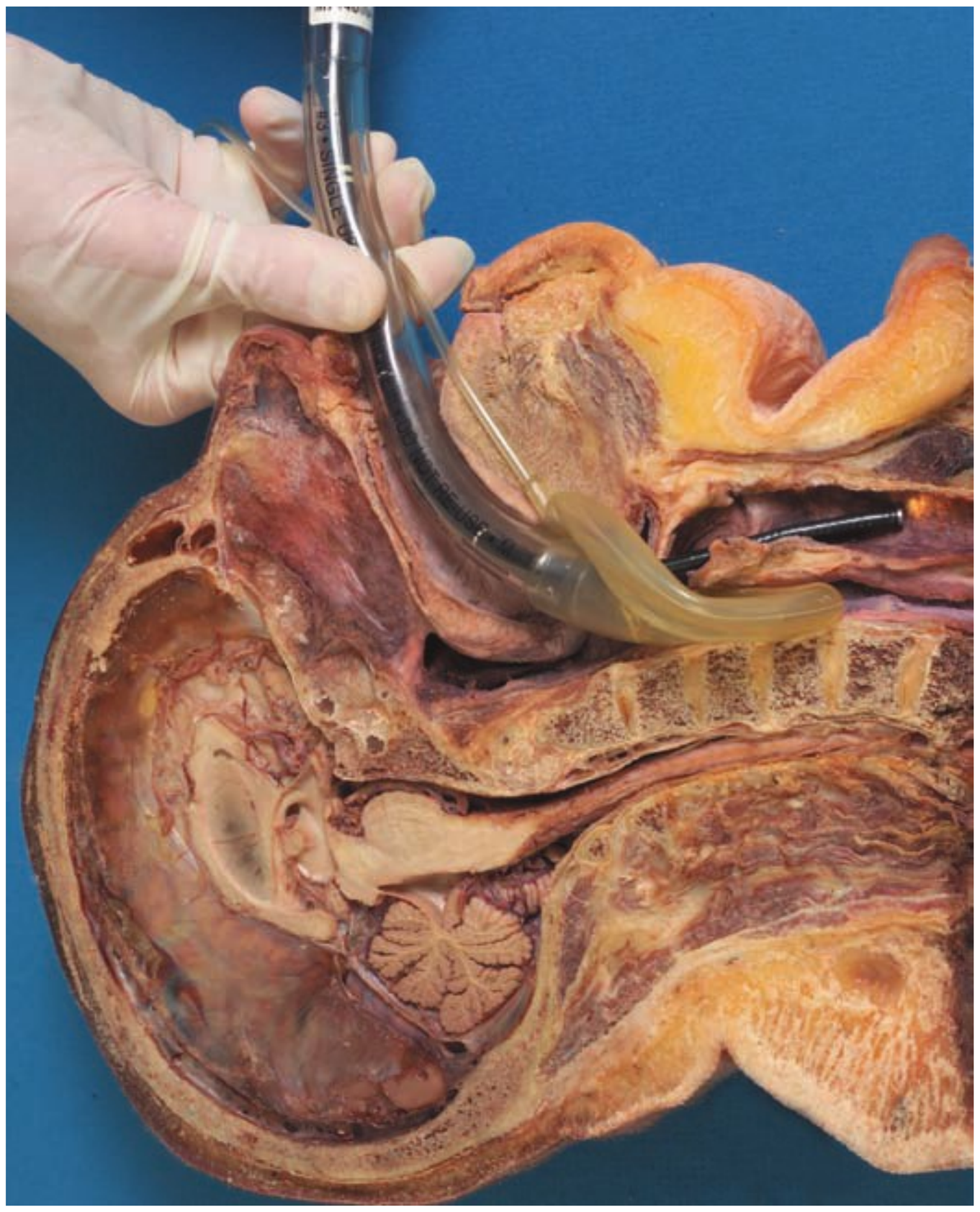


FIGURE 32-1 FOB inserted through LMA into glottis in cadaver specimen.

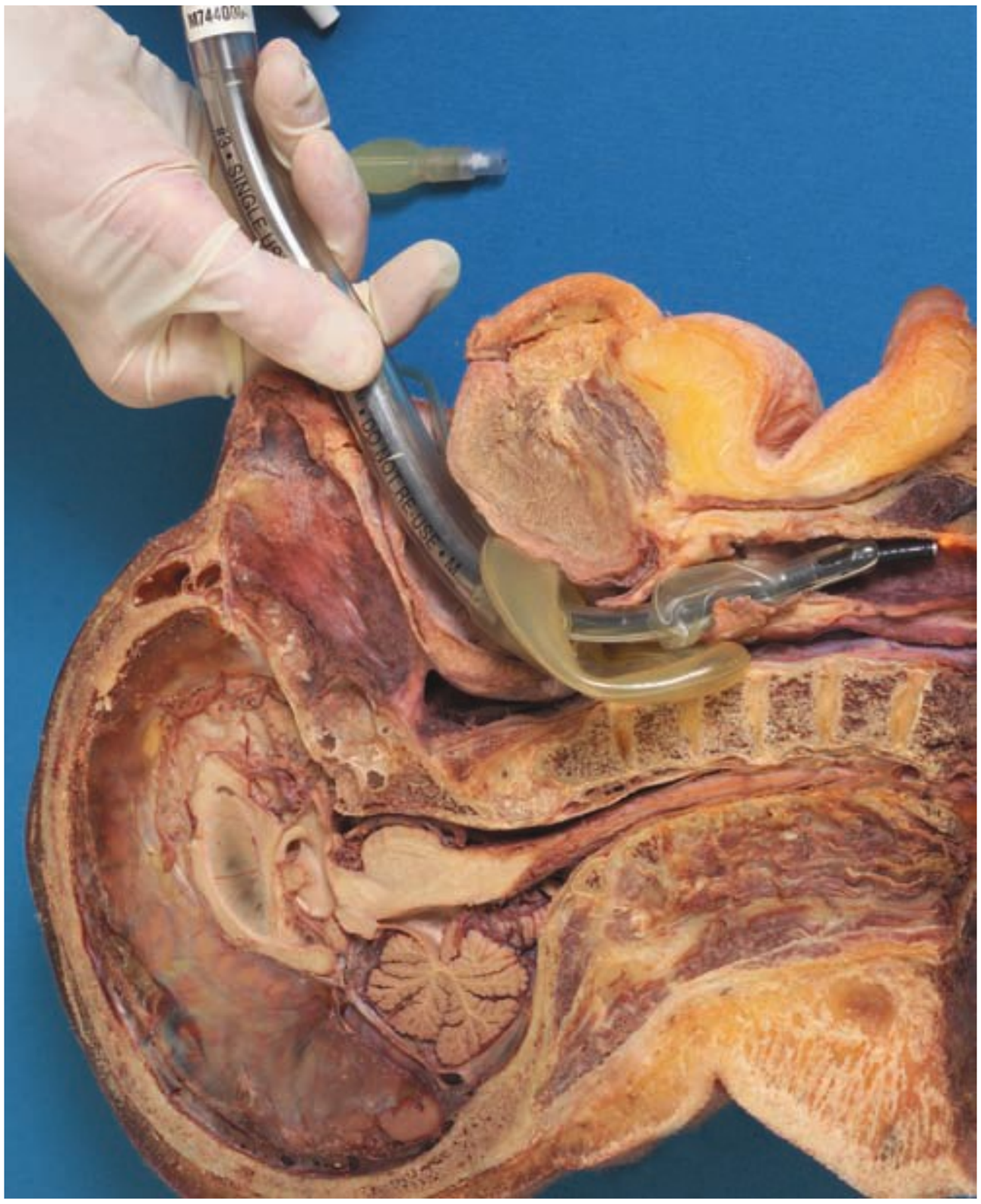


FIGURE 32-2 ETT is pushed through the mask of the LMA, into the larynx. Because of its relatively short length, the 6.0 ETT protrudes only a limited distance into the larynx.

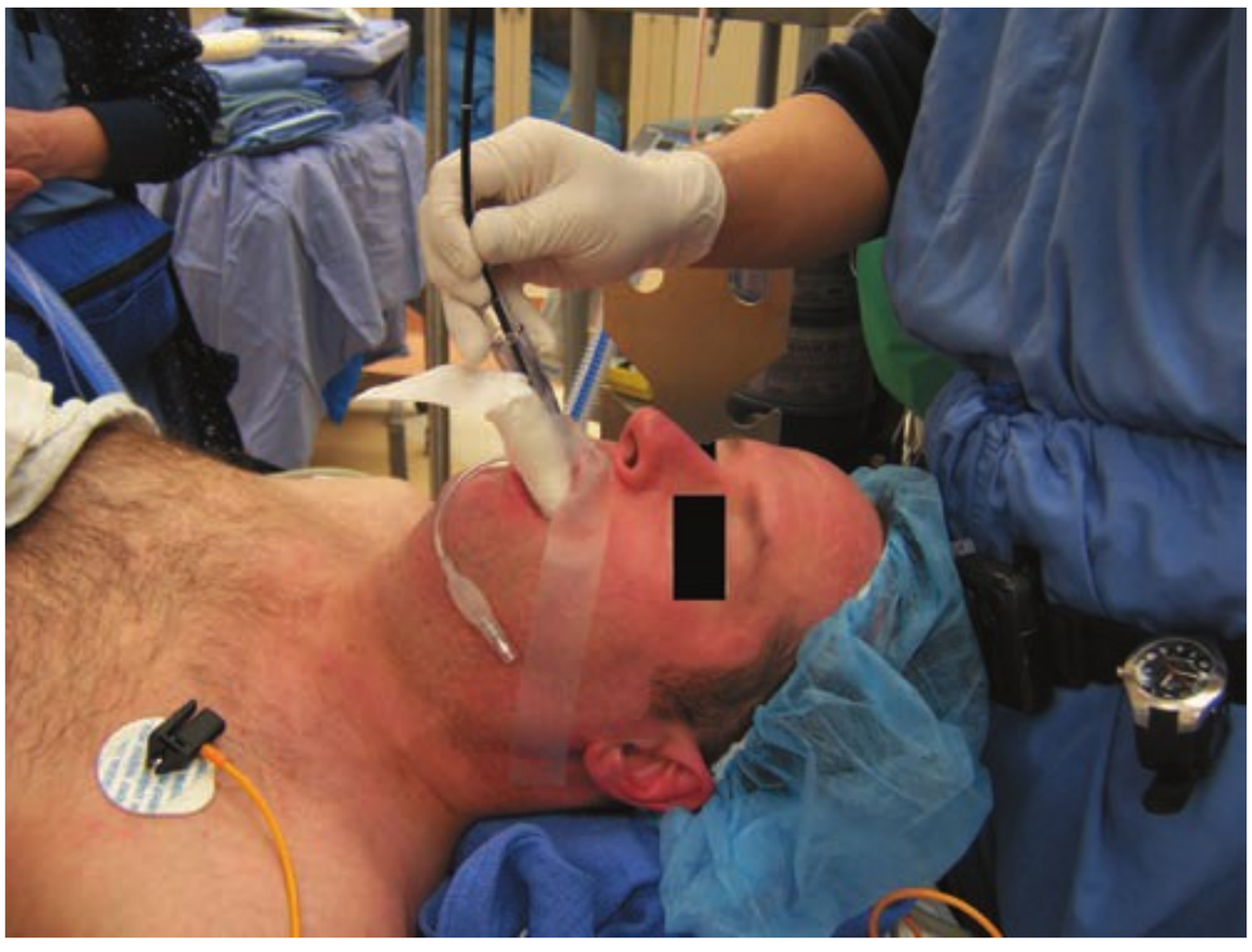


FIGURE 32-3 FOB insertion into LMA after ventilation is optimized.



FIGURE 32-4 Introduction of the 6.0 ETT into the LMA.

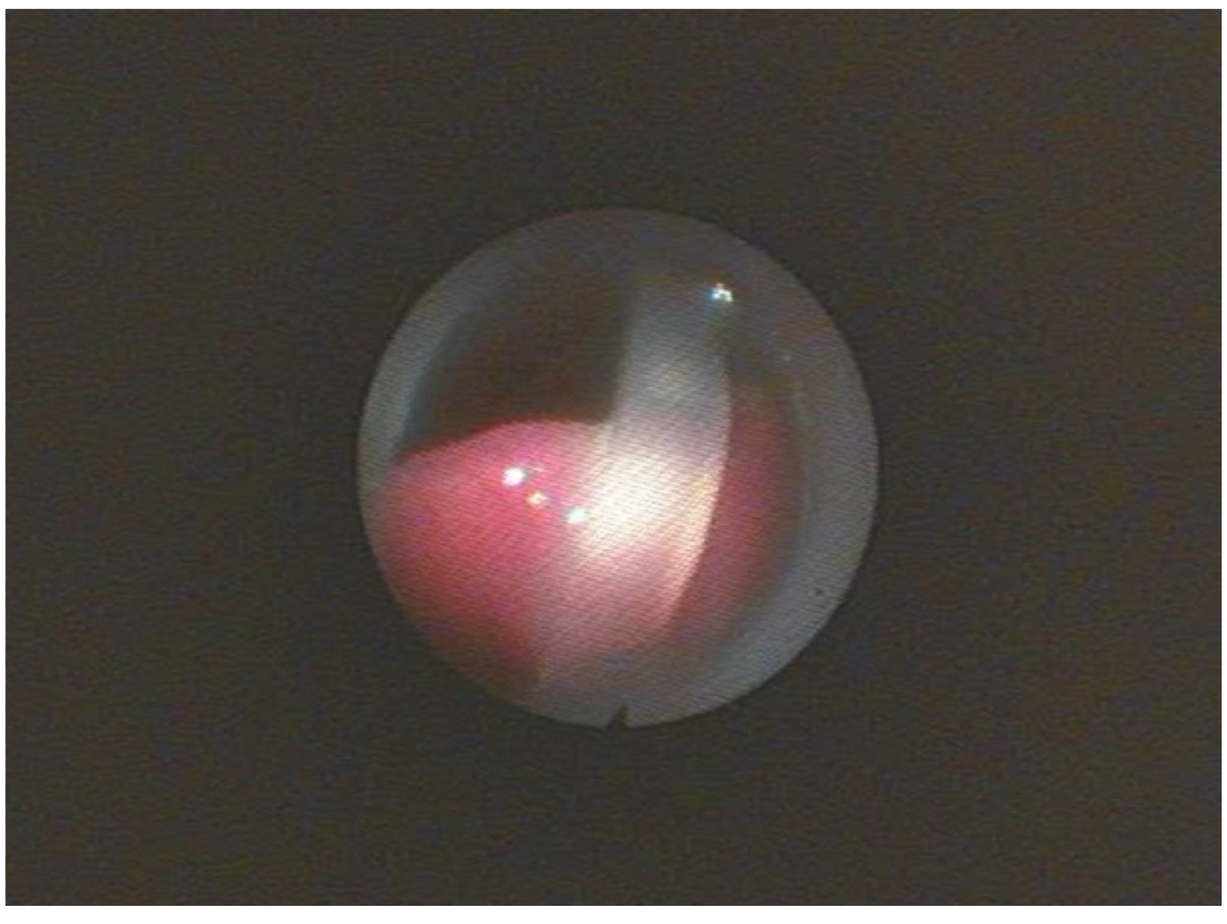


FIGURE 32-5 FOB image from inside the LMA reveals the epiglottis, just beyond the grill which marks the end of the LMA lumen.

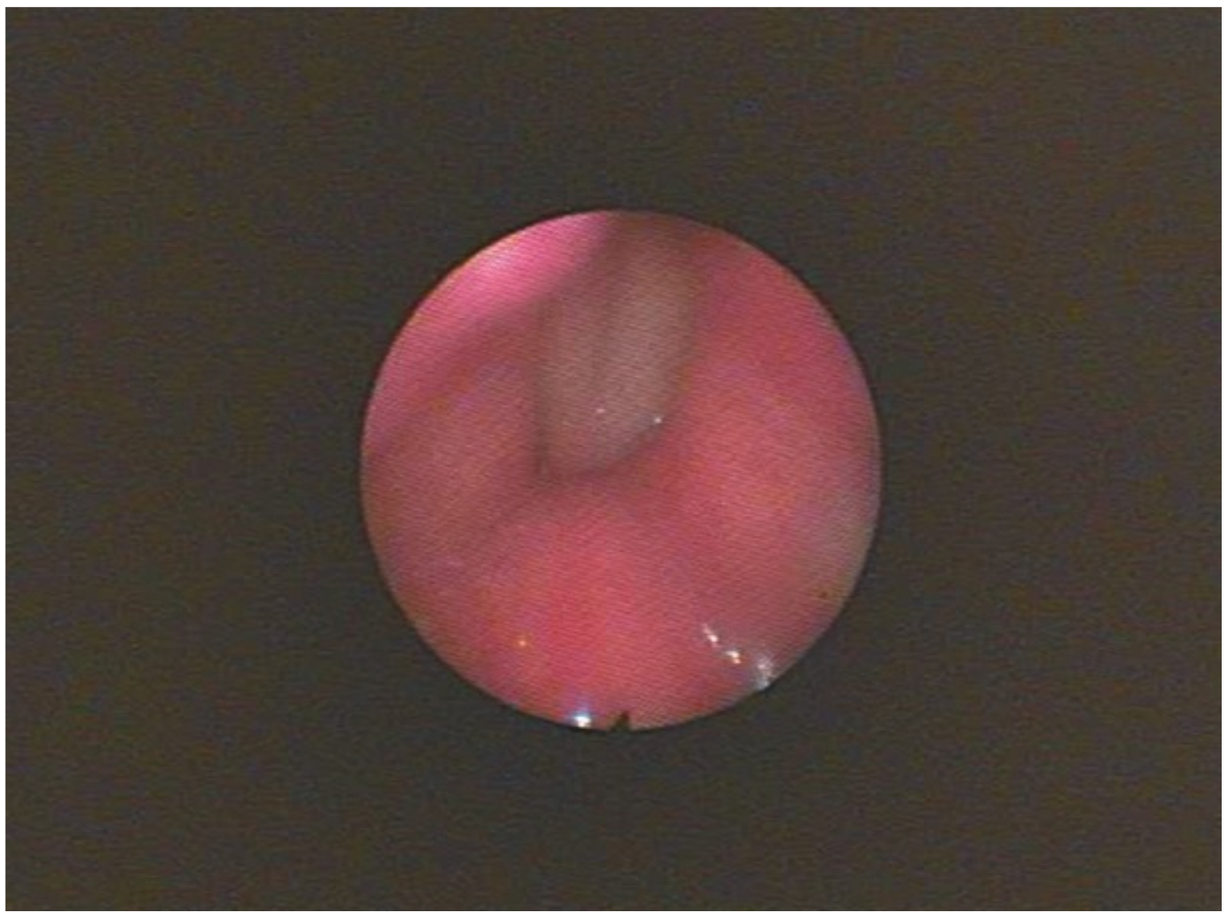


FIGURE 32-6 When the tip of the FOB is advanced through the grill of the LMA, the glottis is usually readily apparent.

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3. Heath ML, Allagain J. Intubation through the laryngeal mask. *Anesthesiology*. 1991;76:545–548.
4. Orebaugh SL. Airway obstruction secondary to prolonged shoulder arthroscopy. *Anesthesiology*. 2003;99:1456–1458.

CHAPTER 33

Flexible Fiberoptic Bronchosope Intubation through the Intubating Laryngeal Mask Airway

Steven L. Orebaugh

Concept

Just as the laryngeal mask airway (LMA) does, the intubating laryngeal mask airway (ILMA) provides an excellent conduit from the mouth to the laryngeal orifice, sitting astride the glottis when properly placed. Some differences between these two ventilation adjuncts exist: the steel barrel of the ILMA makes a right angle as it enters the pharynx, as opposed to the gradual curve of the standard LMA lumen; the distal end of the ILMA lumen is guarded by an epiglottic elevating bar, rather than a grid; and the barrel of the ILMA is larger than that of the standard LMA, as it was designed to facilitate intubation of the trachea. The size 3, 4, and 5 ILMA all permit intubation with an 8.0 internal diameter endotracheal tube (ETT). The provider may insert an ILMA and immediately choose a fiberoptic bronchoscope (FOB) for guided intubation or may choose to attempt blind intubation through the device and call the FOB into play only if this fails.

Evidence

The utility of intubation through the ILMA using FOB guidance has been established through several case series and comparative trials. Joo[1] randomized 38 patients with known difficult airways to either awake intubation with FOB or to intubation after anesthesia with ILMA. In half of the latter group, the patients could not be intubated blindly with ILMA. However, in all of these, FOB was used successfully to intubate through the device. Ferson[2] investigated the utility of ILMA in patients with known or suspected difficult airways (cervical immobilization; failed intubation during direct laryngoscopy; or distorted airway anatomy due to tumor, surgery, or radiation therapy). In 54 of 254 patients, FOB was chosen to guide intubation through the ILMA device from the outset, whereas in the other 200, blind intubation was initiated (up to 5 attempts). The FOB was successful in 100% of the designated cases, on the first attempt. In 7 cases selected for blind intubation, the ETT could not be placed in the trachea, and FOB was used for rescue, which was also successful on the first attempt in all cases.

Preparation

- Same as for ILMA (see Chapter 27)
- Same as for FOB (see Chapter 23)
- Slip ETT over FOB, after lubrication
- The patient should be anesthetized, preoxygenated, in neutral or sniffing position; the procedure may also be conducted in the awake patient with topical anesthesia or nerve blocks to anesthetize the oropharyngeal and laryngeal mucosa

Procedure (Figs. 33-1–33-8)

- Insert ILMA (see Chapter 27)
- Confirm optimum position and ventilation through the ILMA
- Place ETT through ILMA lumen to the 15 cm band (black band around ETT). The tip of the ETT is now lifting the epiglottic elevating bar, facilitating FOB passage into glottis
- Alternatively, place the FOB tip through the ILMA, past the epiglottic elevating bar, into the airway; then advance the ETT
- An FOB elbow adaptor may be attached to the 15-mm ETT adaptor and a breathing circuit likewise attached to allow ongoing ventilation through the ETT/LMA during intubation attempts
- Visualize glottis; enter larynx and trachea with tip of FOB
- Advance the ETT, confirming correct placement with direct visualization through FOB
- Ventilate through ETT for further confirmation
- Remove ILMA device (see Chapter 26)
- Attach circuit to ETT; reconfirm placement with breath sounds, chest rise, and $ETCO_2$
- Secure ETT

Practicality

- Complex and unfamiliar: requires practice in vitro and in vivo
- Expensive (both devices)
- Portability and logistic support are issues with FOB (see Chapter 23)

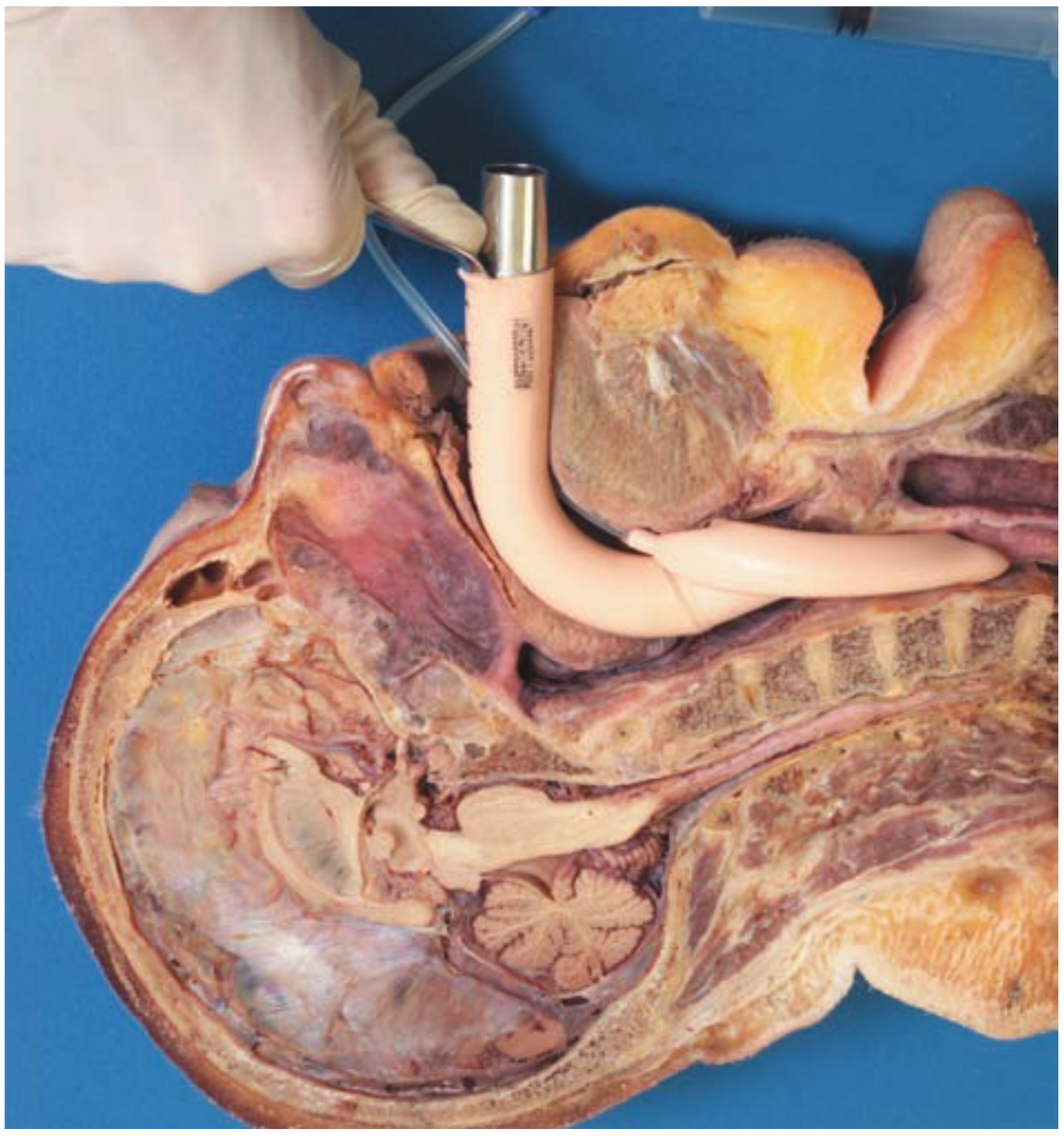


FIGURE 33-1 ILMA in appropriate position in cadaver specimen.

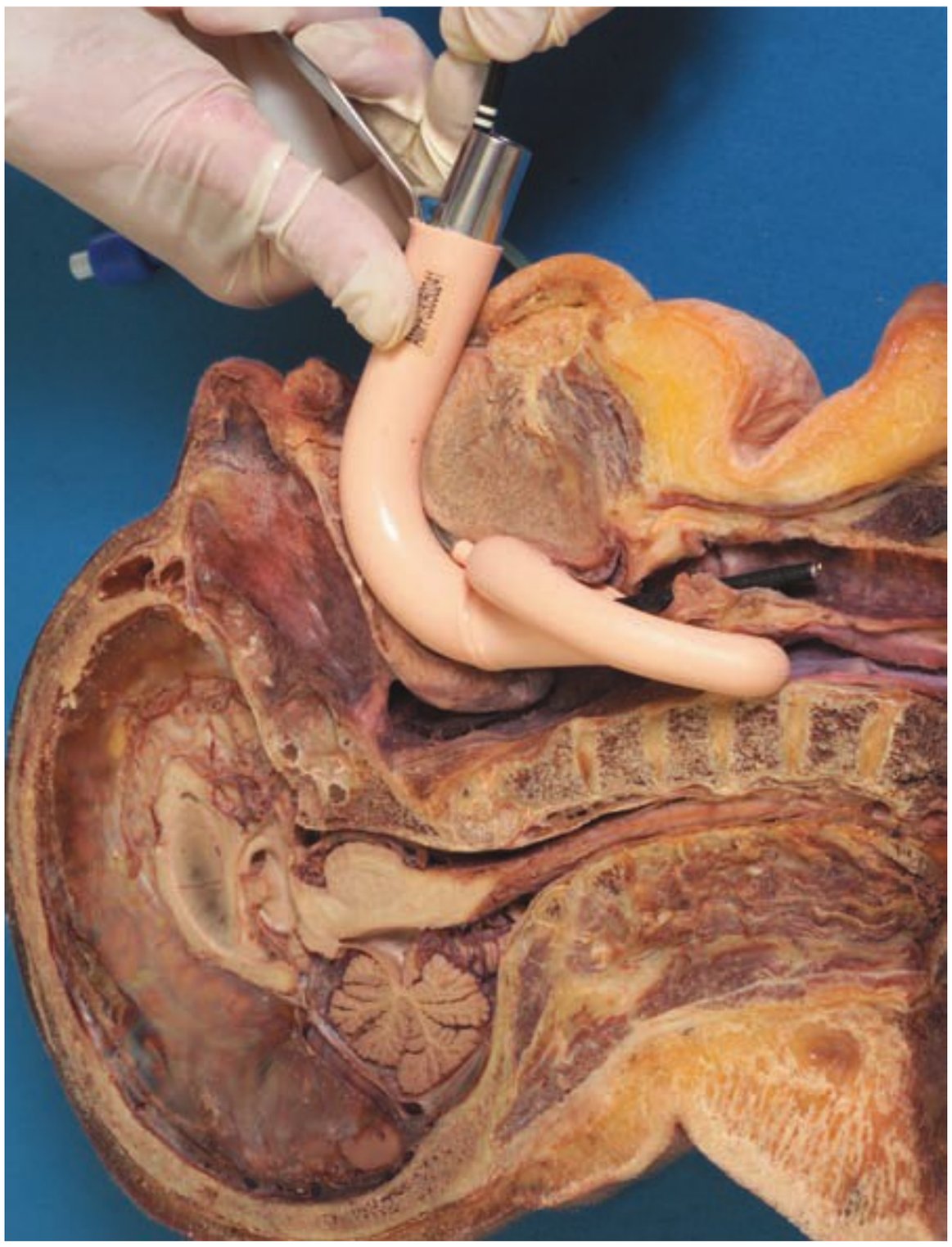


FIGURE 33-2 ILMA with FOB placed through it.

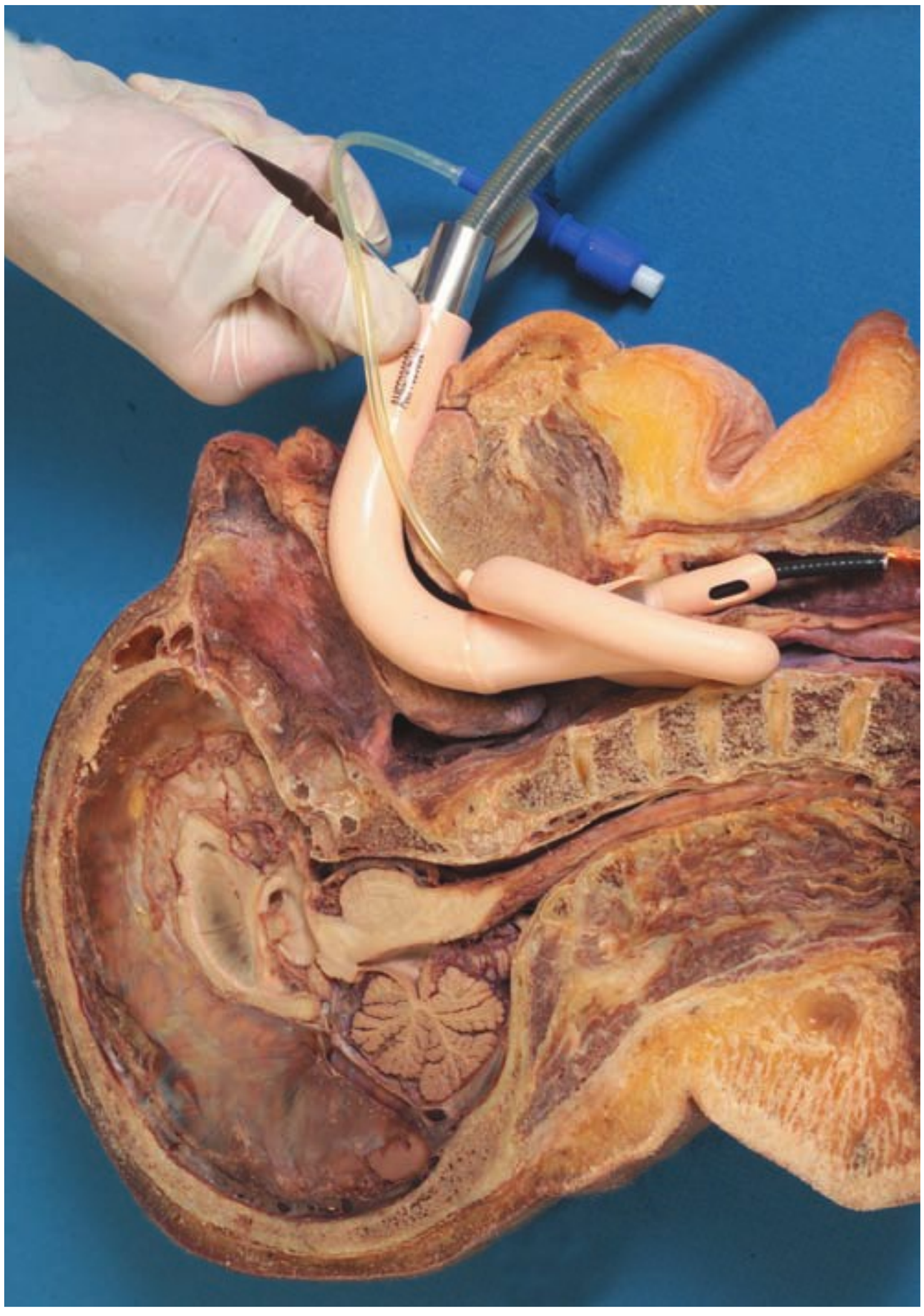


FIGURE 33-3 ETT advanced over FOB through ILMA and into glottis.

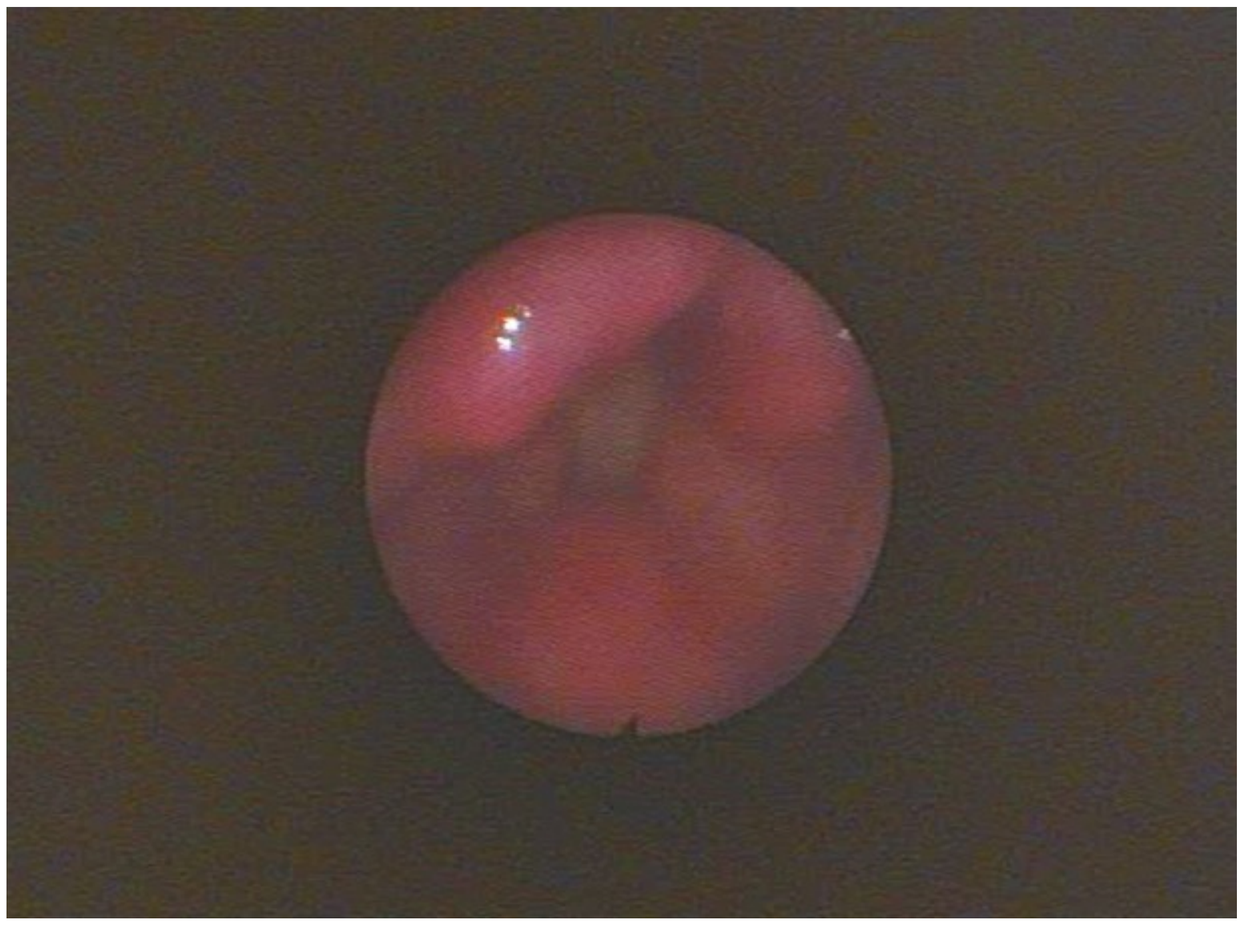


FIGURE 33-4 Image from FOB: glottic opening.



FIGURE 33-5 ILMA is in place; ventilation is confirmed.



FIGURE 33-6 ETT is now inserted through the ILMA, up to the 15-cm mark and just beyond, in order to lift the epiglottic elevating bar out of the way of FOB.



FIGURE 33-7 FOB is inserted through ETT, into airway, and ETT is advanced over the scope, to an appropriate depth.

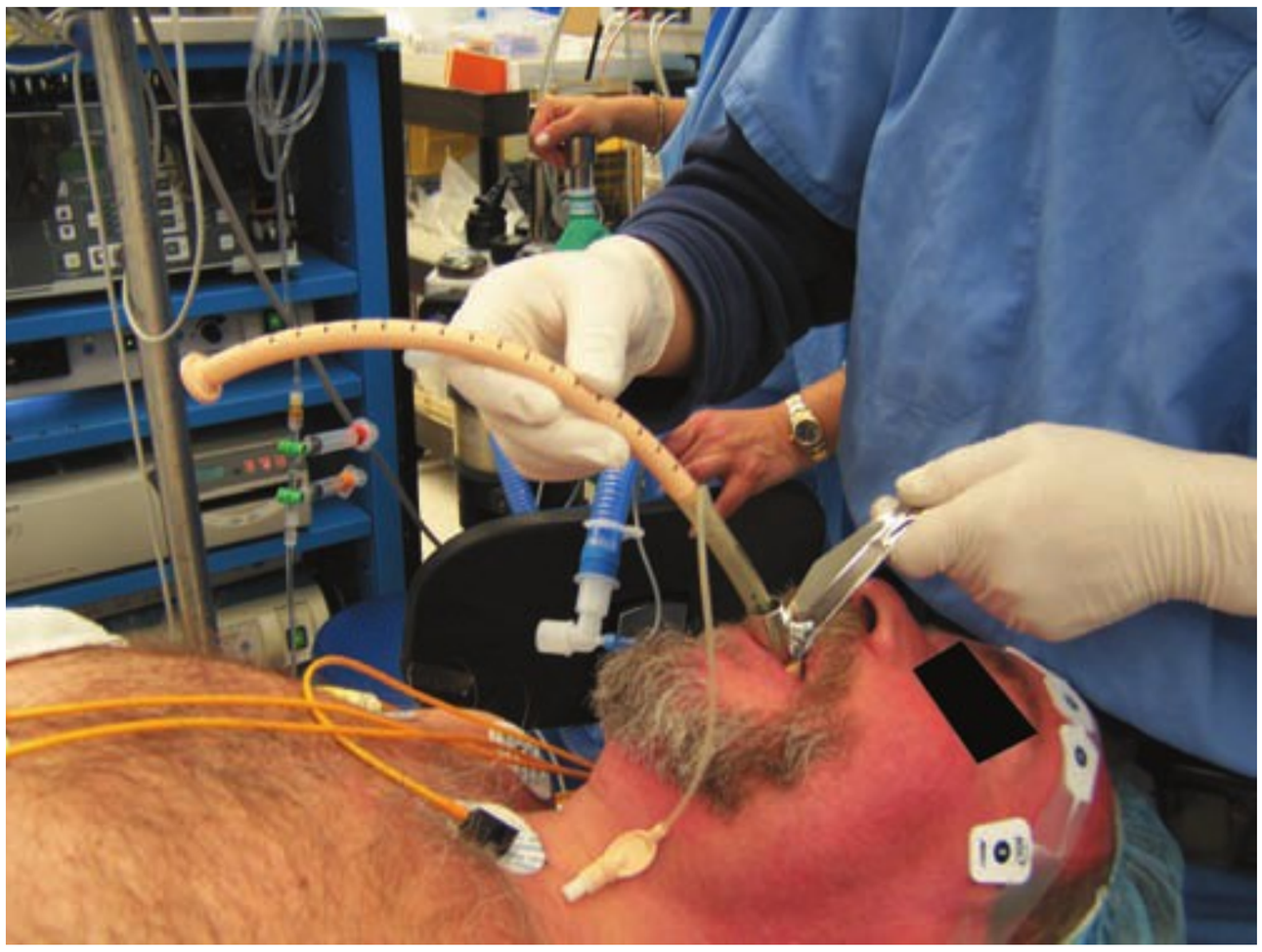


FIGURE 33-8 The scope is used to confirm ETT position, ventilation is also confirmed, and then the ILMA is removed.

Indications

- Failed intubation with blind ILMA attempts
- Failed intubation with direct laryngoscopy
- Failed ventilation (ILMA quickly inserted as rescue device, followed by FOB intubation with ongoing ventilation)

Contraindications

- Copious secretions or blood in airway
- Inaccessibility of oral cavity
- Severe upper airway obstruction

Complications

- Complications of both ILMA insertion and FOB intubation are possible with this combination technique (see Chapters 23 and 27)

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2. Ferson DZ, Rosenblatt WH, Johansen MJ, et al. Use of the Intubating LMA-Fastrach in 254 patients with difficult-to-manage airways. *Anesthesiology*. 2001;95:1175–1181.

CHAPTER 34

Flexible Fiberoptic Bronchoscope Intubation and the Esophago-Tracheal Combitube

Steven L. Orebaugh

Concept

Although the esophago-tracheal combitube (ETC) has been shown to be reliable for mechanical ventilation for long periods,[1] the device is not suitable for ICU care, because it neither permits suctioning of the airway nor does it strictly prevent tracheal aspiration of gastric contents. Furthermore, prolonged inflation of the large oropharyngeal balloon could potentially lead to nerve compression in the oral cavity. A patient with difficult ventilation or intubation in whom an ETC is required will likely require definitive tracheal intubation for continued care in the operating room or critical care units. A fiberoptic bronchoscope (FOB) is a viable option for ensuring safe transition from supraglottic to intratracheal ventilation, without removing the lifesaving ETC device until the endotracheal tube (ETT) is securely in place. The ETC is moved to the left side of the mouth, the oropharyngeal balloon is deflated, and the FOB is inserted. After locating the glottis, the larynx and trachea are entered, and the ETT advanced. If desaturation occurs during the procedure, the oropharyngeal balloon can be quickly reinflated, and ventilation initiated, until oxygen saturations once again permit a brief period of apnea.

Evidence

Evidence for this combination of techniques is limited to anecdotal reports.[2]

Preparations

- Insert ETC (see Chapter 25)
- Prepare for FOB (see Chapter 23)
- Lubricate ETT; load it onto scope
- Anesthetized or unconscious, preoxygenated patient in neutral position, with ongoing ventilation via the ETC

Procedure (Figs. 34-1–34-3)

- Deflate oropharyngeal ETC cuff
- Move the ETC to the left side of the mouth
- Insert FOB into oral cavity, then pharynx
- Visualize the glottis, anterior to the ETC
- Advance FOB into glottis, then into trachea
- Slide ETT over FOB into trachea
- If the ETT cannot be advanced, or the glottis cannot be visualized, the oropharyngeal balloon can be reinflated and ventilation temporarily resumed
- Confirm ETT with breath sounds, $ETCO_2$, and chest rise
- Secure ETT
- Carefully remove the ETC after both cuffs are deflated

Practicality

- Because of the use of FOB, and crowding in the pharynx from the presence of both devices, this is neither simple nor familiar and requires training and practice
- FOB requires logistic support (see Chapter 23)
- Not easily portable

Indications

- Need for ETT after ETC is used for emergent ventilation
- Inability to perform direct laryngoscopy for ETT insertion with ETC in place

Contraindications

- Copious blood or secretions in airway
- Laryngeal trauma

FIGURE 34-1 ETC in place in cadaver specimen.

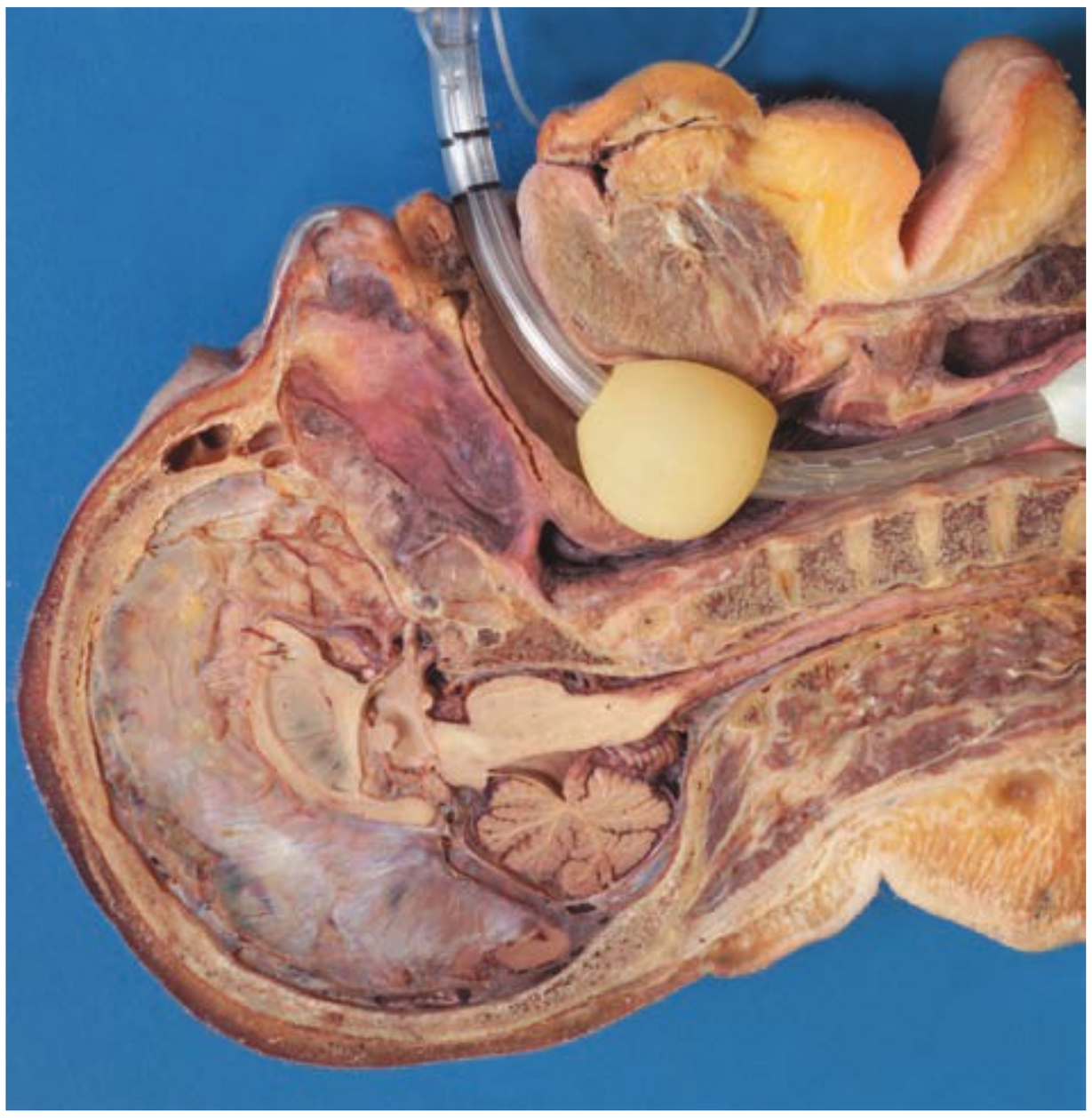


FIGURE 34-2 Insertion of FOB into pharynx, with oropharyngeal cuff down.

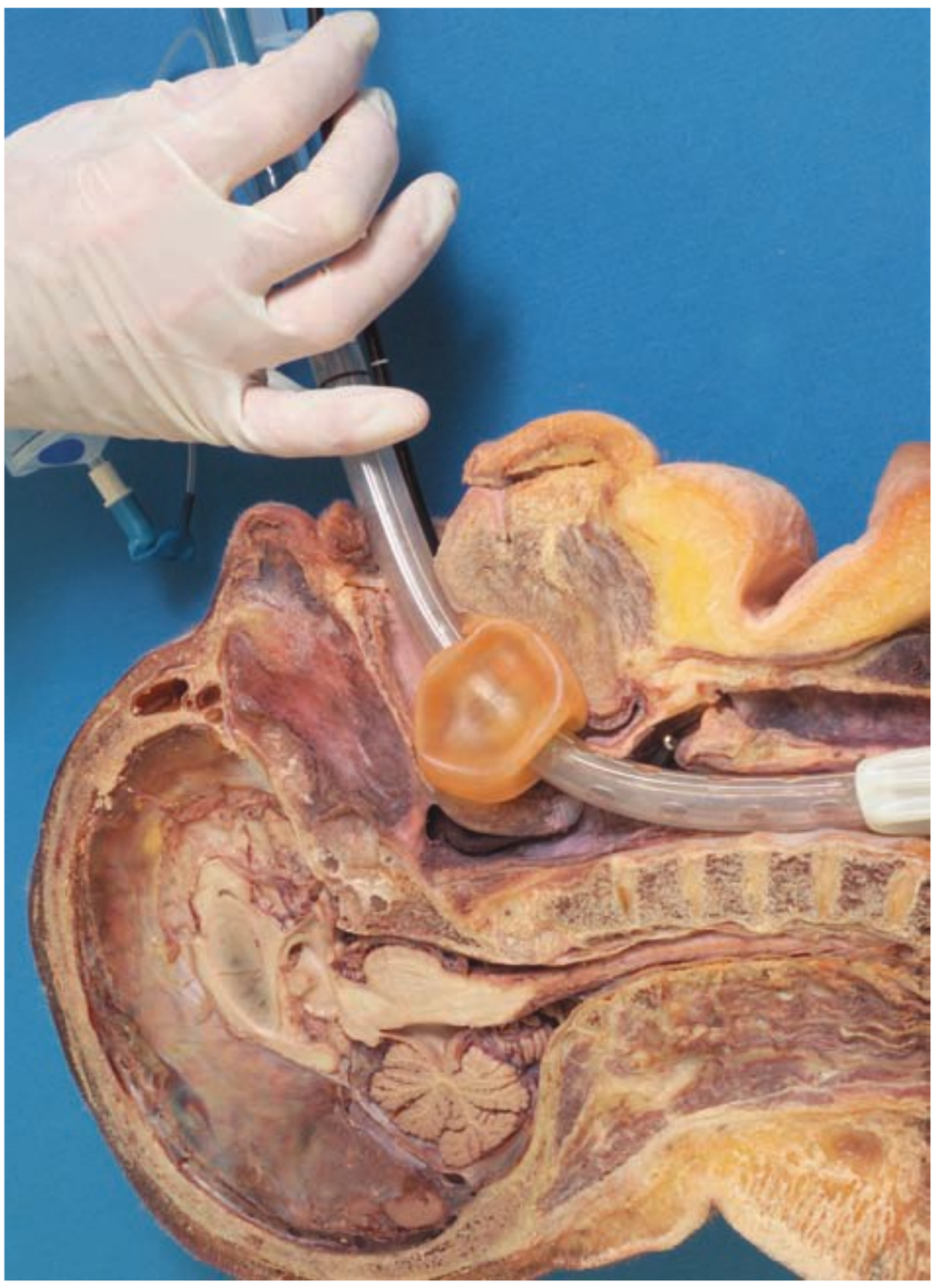




FIGURE 34-3 FOB inserted into larynx, with ETC in place in simulation laboratory.

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1. Frass M. Mechanical ventilation with the esophageal tracheal Combitube in the intensive care unit. *Arch Emerg Med*. 1987;4:219–223.
2. Ovassapian A. Fiberoptic intubation with Combitube in place. *Anesth Analg*. 1993;S315.

CHAPTER 35

Transtracheal Jet Ventilation and Flexible Fiberoptic Bronchoscope Intubation

Steven L. Orebaugh

Concept

Transtracheal jet ventilation (TTJV) is rarely used, but remains an important option in the cannot intubate, cannot ventilate patient, especially if supraglottic ventilation devices (laryngeal mask airway, esophageal-tracheal combitube, perilaryngeal airway, or laryngeal tube) have failed or cannot be inserted. After oxygenation and ventilation with TTJV are established, the airway nonetheless remains unprotected. If the patient cannot rapidly be awakened to resume spontaneous ventilation, or if this is contraindicated, an endotracheal tube (ETT) should be placed to guarantee patency of the airway and protect the patient from aspiration of pharyngeal or gastric contents.

Evidence

The combination of these two techniques is supported by anecdotal evidence.[1,2] The pressures generated by TTJV may serve to stent open the airway, facilitating fiberoptic bronchoscopy (FOB), while permitting ongoing ventilation during the procedure.[1]

Preparation

- Preparation for TTJV (see Chapter 29)
- Preparation for FOB (see Chapter 23)
- Anesthetized, preoxygenated patient in neutral position, with head extension

Procedure (Figs. 35-1–35-4)

- Place catheter through cricothyroid membrane and establish ventilation with TTJV (see Chapter 28)
- Remove oral airway, if in place (nasal airways should remain to promote effective exhalation of air)
- Attempt direct laryngoscopy (place ETT if glottis is visible)
- Assistant should continue direct laryngoscopy, to maintain patency of airway for expired gases, or an oral airway (such as Ovassapian airway) can be used to facilitate FOB
- Additionally, a jaw thrust should be maintained by assistant (in the absence of direct laryngoscopy)
- Insert FOB into pharynx
- Locate glottis and advance FOB into trachea
- Avoid hitting or kinking the TTJV catheter
- Advance ETT into airway
- Remove FOB; confirm that ETT is in trachea
- Attach circuit, confirm $ETCO_2$, chest rise, breath sounds
- Inflate ETT cuff
- Discontinue TTJV; ventilate through ETT
- Remove TTJV catheter; fix ETT in place
- Note: this procedure can also be applied with nasal FOB, if the mouth cannot be opened

Practicality

- Not familiar or simple: requires training and practice in assembling components and experience with FOB in patients or simulators
- Expensive due to incorporation of FOB
- Portability and logistics are an issue due to FOB (see Chapter 23)

Indications

- Patient with ongoing TTJV, who requires definitive airway
- Patient undergoing TTJV, who has proven to have poor view at direct laryngoscopy
- Predicted difficult airway

Contraindications

- Copious blood/secretions in airway
- Inaccessibility of oral cavity (nasal route may be chosen)
- Other contraindications of TTJV (see Chapter 29)

Complications

- Complications of both TTJV and FOB intubation are possible with this combined technique (see Chapters 23 and 29)

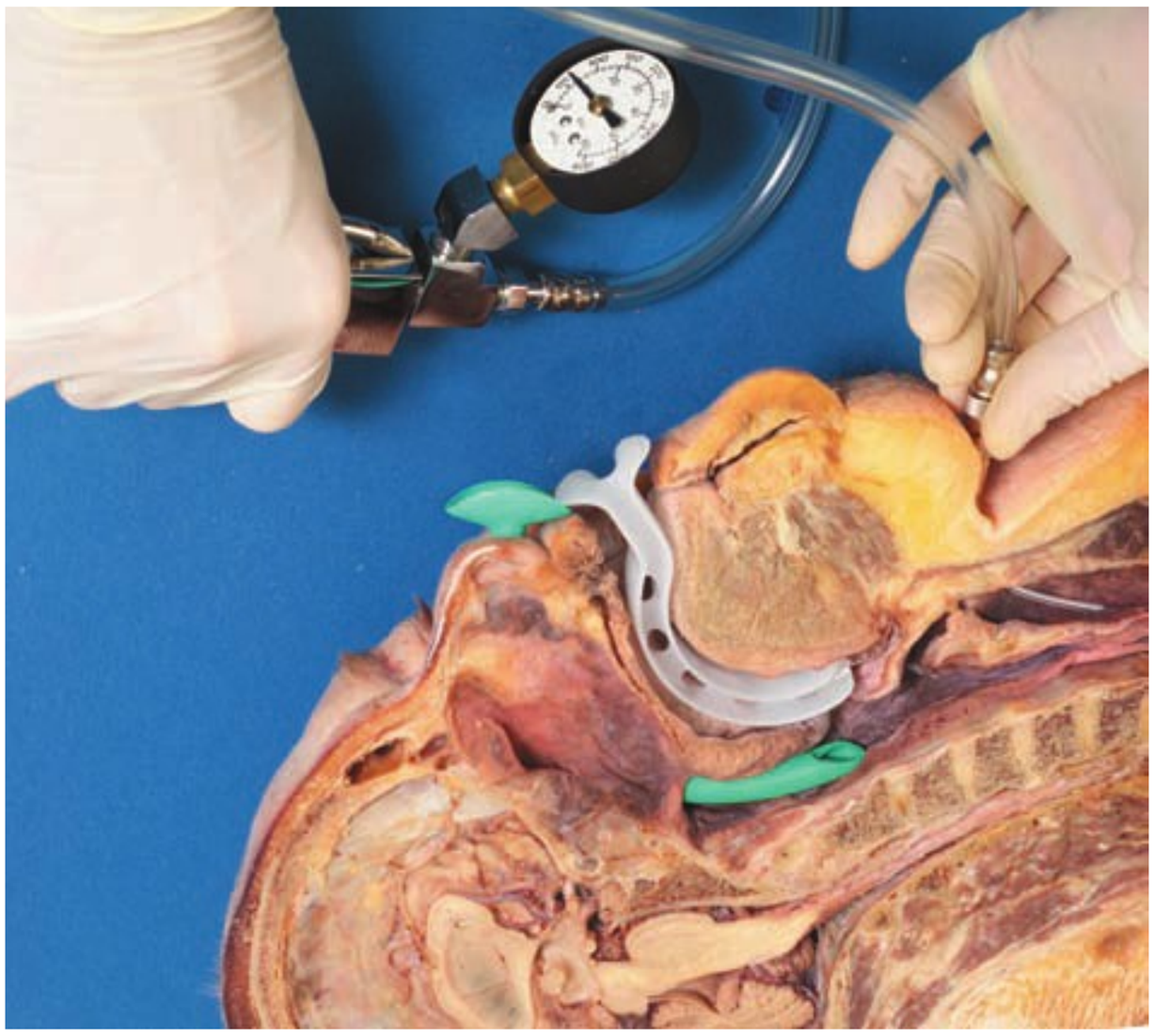


FIGURE 35-1 Ongoing TTJV simulated in a cadaver specimen.

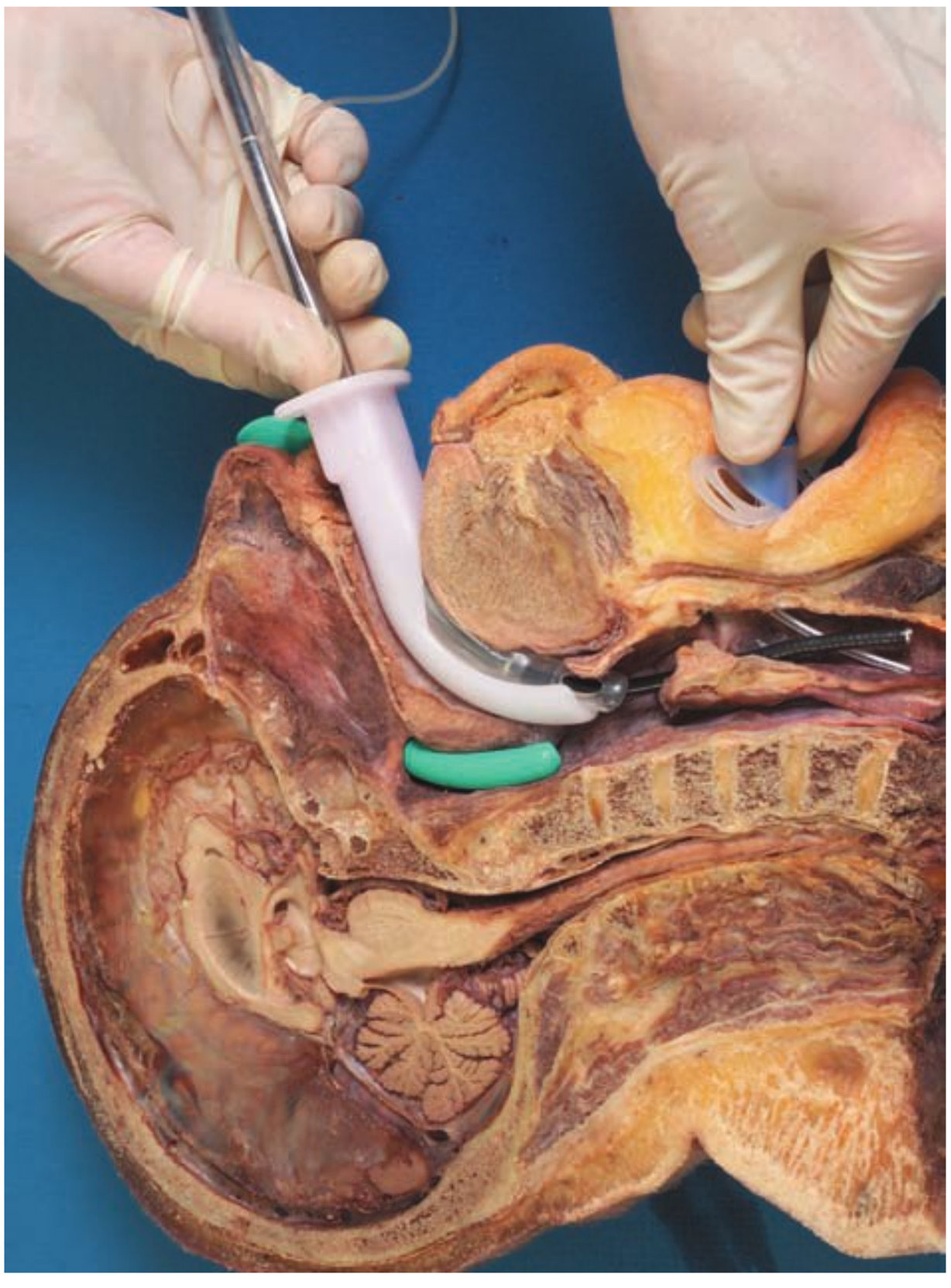


FIGURE 35-2 Insertion of FOB into larynx, taking care to avoid kinking the TTJV catheter.



FIGURE 35-3 Advancement of ETT over FOB and into trachea.



FIGURE 35-4 In this simulation, ongoing TTJV is shown (note oral and nasal airway in place to allow escape of gas) as a FOB is used to carry out oral ETT placement.

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PART X

Emergency Surgical Airways

CHAPTER 36

Cricothyrotomy

Brian Gierl and Todd Oravitz

Concept

Cricothyrotomy (also cricothyroidectomy or coniotomy) is the insertion of a tracheal tube through an incision in the cricothyroid membrane (CTM) in order to establish a rapid, definitive airway. Although discouraged in the early part of the 20th century because of complications, chiefly subglottic stenosis, cricothyrotomy was reestablished as a safe technique for airway management after publication of the work by Brantigan and Grow. They documented an acceptable complication rate of 6.1%, among a series of 655 procedures.[1] This compares well to the published rate of tracheostomy complication of 6.6% for bleeding and 5.7% for surgical site infection; these were comparable for both a percutaneous and surgical technique.[2]

Cricothyrotomy is most commonly used when both intubation and ventilation fail; in situations such as foreign-body obstruction; superior laryngeal trauma; inhalation, thermal, or caustic injury to the upper airway; angioneurotic edema; upper airway bleeding; epiglottitis and croup. Its use has also been advocated for patients with anatomy that would otherwise complicate tracheostomy, such as increased cervical girth, an abundance of pendulous, submental fat, or an entirely intrathoracic trachea in a patient with restricted cervical range of motion; a small case series of such patients did not reveal any complications.[3]

The classic technique involves a vertical midline incision over the thyroid and cricoid cartilages to expose the CTM, followed by a transverse incision through the CTM. The medial portion of the CTM is commonly referred to as the cricothyroid ligament, whereas the underlying and wider membrane is known as the conus elasticus.[4] The vertical incision allows the operator to extend the incision in order to obtain appropriate exposure while minimizing the risk of vascular injury. Neck veins may course within 1 cm of midline in 30% of patients (Fig. 36-1), whereas midline arteries occur in less than 5% of patients.[5] Cricothyrotomy may also be carried out with a single transverse incision through skin and CTM, if the interval is readily palpable.[1,6] The incision is placed across the lower third of the CTM to avoid the cricothyroid artery, which transverses the internal aspect of the upper third of the membrane and may cause unrecognized bleeding and aspiration.[7]

Cricothyrotomy is not recommended in children under 8 years of age due to multiple anatomic differences when compared with the adult airway, including a hyoid bone that is more prominent than the thyroid cartilage, cephalad CTM displacement, and a smaller CTM. Specifically, the dimensions of the neonate's CTM is only 2.6 × 3.0 mm, making the passage of even a neonatal endotracheal tube (ETT) difficult, without causing cartilaginous injury, edema, or hemorrhage in the airway.[8]

Evidence

Cricothyrotomy is effective for establishing an emergency airway[1] but does carry a risk of acute and chronic complications. Bleeding, failure to secure the airway, and pneumothorax may complicate this procedure, which is typically carried out rapidly and often under duress. Because of its invasive and emergent nature, cricothyrotomy is not subject to randomization in trials of airway management, and most evidence is in the form of case series. Recent data suggest that, even in the emergency department, where major trauma and other emergent indications for surgical airways are likely to be higher than in other settings, the incidence of surgical airways approximates only 1% of all intubations.[9–11] This is likely due to the success of rapid sequence intubation with direct laryngoscopy as the preferred means of managing the airway,[9] the improved training of emergency medicine residents in airway management, and the lower frequency of resuscitation of blunt trauma victims with no detectable vital signs.[12] In the face of falling rates of cricothyrotomy, it has become difficult to maintain proficiency in, and to teach, this essential skill.[13]

Success rates are quite high in skilled hands, usually above 90%, though these may be considerably lower when carried out by inexperienced personnel.[14–16] Reported acute complication rates for emergent cricothyrotomy are between 6% and 40%.[1,14–16] In Brantigan and Grow's[1] landmark study, chronic subglottic stenosis did not occur

after any of their 655 procedures, but in a meta-analysis of reports from 1978 to 2008, there was a reported rate of chronic subglottic stenosis of 2.2% after cricothyrotomy.[17] In another study, there were no long-term complications among 27 patients.[14]

Traditional cricothyrotomy may be complicated by patient factors, including obesity, although neither patient cervical girth nor sternomental distance correlated with the ability of a senior otolaryngology resident's ability to palpate the cricoid cartilage.[18] In one study, it was found that anesthesiologists poorly identified the CTM by palpation.[19] Emergency medicine physicians have developed a technique that used ultrasound to quickly identify the CTM and appropriate structures for cricothyrotomy.[20]

In the prehospital realm, Spaite[21] described attempted cricothyrotomy in 16 patients with an 88% success rate as well as a complication rate of 31%. Boyle, in a retrospective study of cricothyrotomy by flight nurses in a teaching hospital helicopter transport program, described 69 cricothyrotomy attempts among 2,108 patients transported. The success rate was 98.5%, with a much lower acute complication rate of 8.7%.[22]

Preparation (Figs. 36-2 and 36-3)

- Prepare tools: no. 11 blade, small ETT (5.5 or 6.0 cuffed) and hemostat, at a minimum, or a full-fledged tracheostomy set, with tracheostomy tube, if available. A tracheal hook is also desirable
- Test cuff and pilot balloon of ETT or tracheostomy tube, if used. The obturator of the tracheostomy tube should be in place to facilitate insertion
- Locate and palpate CTM
- Apply antiseptic solution to anterior neck
- Sterile draping (if time allows)
- Anesthetized, preoxygenated patient in neutral position
- Subcutaneous local anesthetic if necessary (if patient is not unconscious)

Procedure (Figs. 36-4–36-14)

- Grasp thyroid cartilage firmly with long finger and thumb, palpating CTM with index finger of same hand
- With the other hand, incise through the skin, vertically, 2 to 3 cm, from thyroid prominence to inferior border of cricoid cartilage. A vertical incision can be extended to obtain adequate exposure of the CTM
- Manually retract skin and subcutaneous tissue
- Reidentify the CTM with index finger
- Incise horizontally, 1 to 1.5 cm through lower portion of the CTM
- *Alternatively, make a single 1.5-cm incision transversely through the skin, subcutaneous tissue, and inferior portion of the CTM, without a vertical incision if the anatomy is well defined
- Spread CTM with hemostat, or place a tracheal hook and pull upward on the thyroid cartilage, allowing placement of Trousseau dilator
- Dilate the cricothyrotomy opening, from superior to inferior, with hemostat or dilator
- Insert ETT or tracheostomy tube between blades of dilator or hemostat. Gentle rotation of dilator as tube is placed facilitates tube entry and advancement in a caudad direction into the trachea



FIGURE 36-1 A network of veins evident in the subcutaneous tissue over the cricothyroid interval (photo by David Pinkerton).

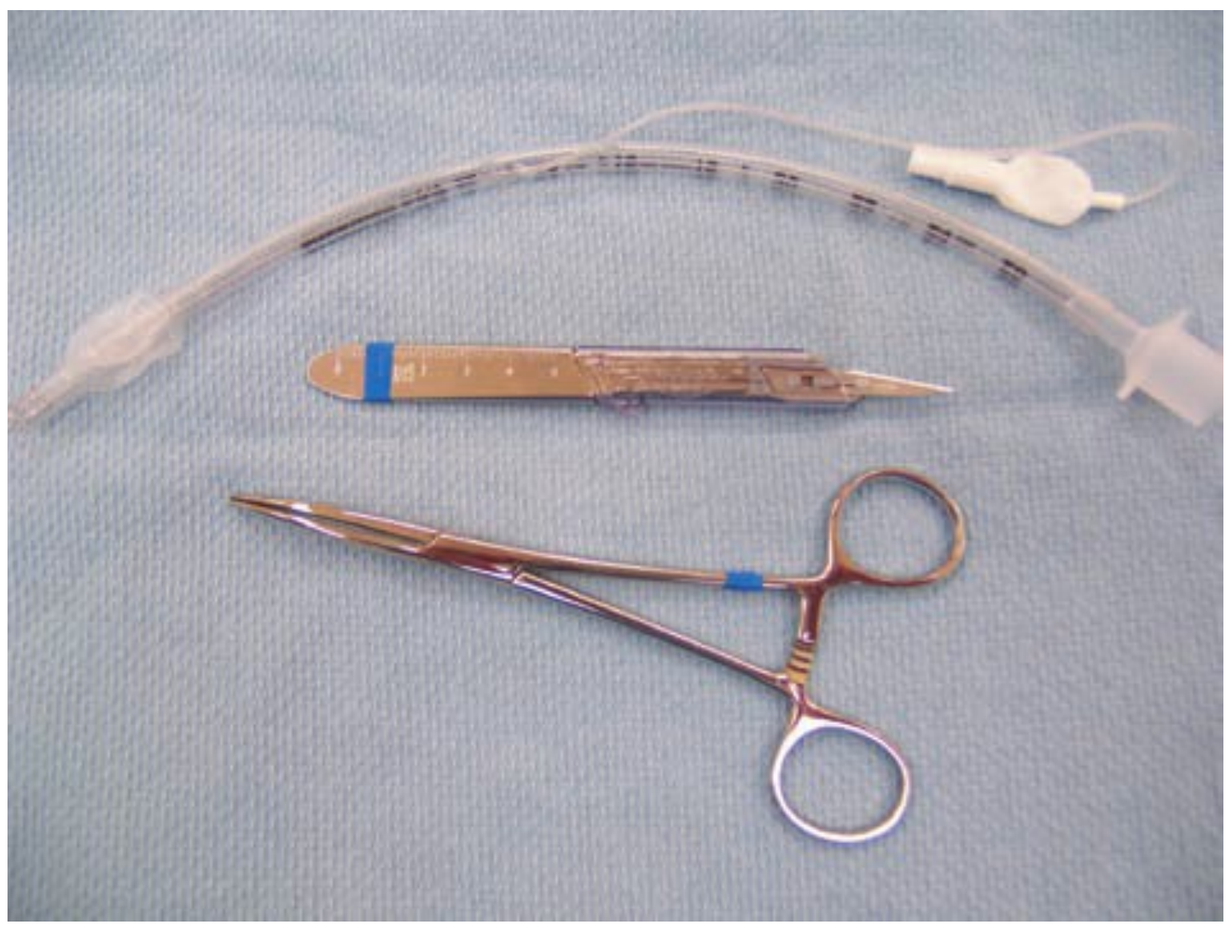


FIGURE 36-2 "Poor Man's Cricothyrotomy set": a scalpel, hemostat, and small ETT can be used to carry out a surgical airway if a formal set is not available.



FIGURE 36-3 Standard tracheostomy set.



FIGURE 36-4 Grasping the larynx while palpating the CTM.

- Remove obturator of tracheostomy tube, inflate cuff of tracheostomy or ETT, ventilate, and confirm position in airway
- Secure tube in place with tape, sutures, or collar and ties
- Obtain chest X-ray for tube placement

Practicality

- Due to declining rates of surgical airways, cricothyrotomy is unfamiliar to most: requires anatomic knowledge and surgical skills; practice with animals or cadavers is desirable
- Inexpensive
- Portable
- "Final common pathway" for lifesaving ventilation when all else fails

Indications

- Failure to intubate or ventilate by other methods
- Facial, head, or neck trauma, when other means of intubation are precluded or impractical
- Laryngeal trauma above the CTM
- Inaccessibility of oral cavity (if nasal intubation fails or is impractical)

FIGURE 36-5 Dissection of cadaver specimen, revealing the strap muscles covering the larynx and CTM.



FIGURE 36-6 Palpation of CTM.





FIGURE 36-7 Horizontal incision in lower portion of CTM. Vessels crossing the membrane are more likely to be encountered at its cephalad extent.



FIGURE 36-8 Dilator or hemostat is used to enlarge the incision in the CTM after incision (a tracheal hook is helpful to pull the thyroid cartilage upward and toward the patient's head, enhancing the cricothyrotomy before the dilator is placed).



FIGURE 36-9 Tracheal tube (ETT or tracheostomy tube) is inserted into cricothyroid interval.

- Severe upper airway obstruction
- Foreign-body obstruction
- Inhalation, thermal, or caustic injury to the upper airway
- Angioneurotic edema
- Upper airway bleeding
- Epiglottitis and croup

Contraindications

- Unrecognizable anatomic landmarks
- Coagulopathy (relative)
- Laryngotracheal disruption with retraction of the distal trachea into the mediastinum
- Child less than 8 years of age (formal tracheostomy is preferred)
- Laryngeal pathology (stenosis, cancer, infection; all relative)
- Lack of familiarity with technique (relative)

Complications

- Bleeding including blood obscuring CTM followed by placement and cricothyrotomy failure
- Infection
- ETT misplacement
- Laryngeal trauma
- Esophageal perforation
- Subcutaneous emphysema
- Pneumothorax
- Voice change, vocal cord injury
- Subglottic stenosis
- Tracheoesophageal fistula



FIGURE 36-10 After confirmation of ETT (or tracheostomy tube) position in the airway, ventilation can begin.



FIGURE 36-11 Instead of a single horizontal incision over the CTM, a midline vertical incision can be carried out first, over the thyroid and cricoid cartilages, as shown.

(Courtesy of Dr. Samuel Tisherman, Department of Surgery, University of Pittsburgh School of Medicine.)



FIGURE 36-12 After the vertical incision, the skin and subcutaneous tissues are retracted and the CTM relocated with the index finger. A horizontal incision is then made through the CTM.

(Courtesy of Dr. Samuel Tisherman, Department of Surgery, University of Pittsburgh School of Medicine.)



FIGURE 36-13 A Trousseau dilator (or hemostat) is then used to further open the incision through the CTM.

(Courtesy of Dr. Samuel Tisherman, Department of Surgery, University of Pittsburgh School of Medicine.)



FIGURE 36-14 As shown, a tracheostomy tube, or an ETT, is inserted into the opening.

(Courtesy of Dr. Samuel Tisherman, Department of Surgery, University of Pittsburgh School of Medicine.)

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CHAPTER 37

Wire-Guided Cricothyrotomy

Adam J. Munson-Young and Ivan V. Colaizzi

Concept

Using a concept similar to the Seldinger technique for vessel cannulation, a wire-guided cricothyrotomy approach can serve as a reliable and timely method for creating access to the airway in an otherwise dire situation. Compared with the conventional open tracheostomy approach to establishing an airway, wire-guided cricothyrotomy requires far less surgical skill and employs a wire-exchange technique that is often familiar to nonsurgical practitioners. This method of establishing an airway in an emergency situation is accomplished by puncturing the cricothyroid membrane (CTM) with a thin-walled needle.[1] After aspiration of air confirms the location of the needle within the trachea, a wire is passed through the needle. The needle is subsequently withdrawn, leaving the wire in place. A small skin incision is made over the wire, which facilitates dilation and placement of an airway catheter into the trachea. Once inserted, the dilator is removed and the airway catheter is left seated within the airway. This sequence, known as the Seldinger technique, has been shown to reduce insertion-related complications, including cartilagenous injury and bleeding, and to increase rates of success for placement of an emergency airway.[2] Commercially available kits commonly used include the Melker Emergency Cricothyrotomy Kit and Arndt Emergency Cricothyrotomy Set (Cooke Critical Care, Bloomington, IN, USA).

Other percutaneous emergency cricothyrotomy sets use a catheter-over-needle technique, where wire insertion is not used to facilitate airway placement. Rather, an airway is placed directly into the trachea by threading it over a needle. Examples of these kits include the QuickTrach (VBM Medizintechnik GmbH, Sulz am Neckar, Germany) and the Patil Emergency Cricothyrotomy Catheter Set (Cooke Critical Care, Bloomington, IN, USA).

Evidence

Many studies have evaluated the wire-guided technique in comparison with other accepted methods of emergently establishing an airway. Chan et al[3] compared open surgical cricothyrotomy and the Melker wire-guided method, evaluating procedural success rates and practitioner technique preference. Nearly all (94%) of the participants preferred the wire-guided technique over open crithothyrotomy, and succes of airway placement was similar for both groups. Eisenburger et al[4] conducted a study measuring the success and efficiency of open surgical cricothyrotomy against the wire-guided technique. No significant differences were found with regard to success rates, procedure time, or injury rates. Fikkers et al[5] compared the wire-guided technique with the catheter-over-needle approach when performed by resident physicians. No significant difference was found between the two groups, as successful placement of an airway occurred in 85% and 95% of the attempts, respectively.

The limitations of this technique have been recognized, making proper patient selection and positioning paramount for optimizing successful completion of the procedure.[6] Barkhuysen et al concluded that the wire-guided method for cricothyrotomy is not preferred in patients with severe maxillofacial trauma who rely on the prone or sitting position with anteflexion of the neck to maintain patency of the airway. Wire-guided cricothyrotomy has also been criticized as being more time intensive than other percutaneous approaches as there are multiple necessary steps for proper placement.[7,8] However, emerging data suggest that the technique remains both effective and efficient.[7] Metterlein et al report that compared with a catheter-over-needle technique, wire-guided cricothyrotomy carries reduced risk of posterior tracheal wall mucosal injury and also enhances the opportunity for correct placement upon first attempt.

Preparation (Fig. 37-1)

- Same as for cricothyrotomy (see Chapter 36)
- Open kit, test-fit components (syringe, needle, wire, tracheostomy tube, and obturator/dilator)
- Palpate and mark CTM
- Anesthetized, or unconscious, preoxygenated patient (also, the technique may be carried out in a conscious patient, with local anesthesia injected into the skin and subcutaneous tissue over the CTM)

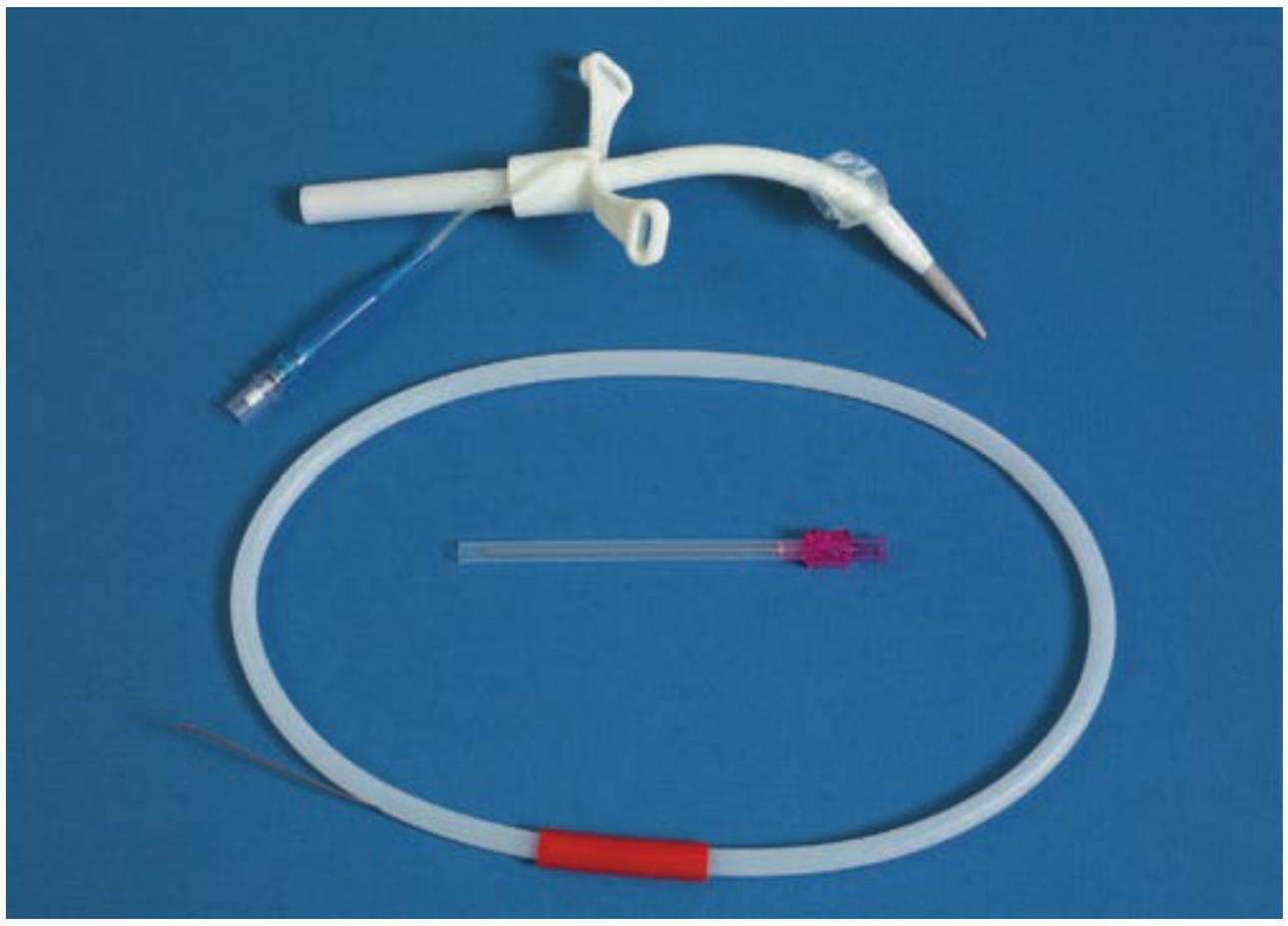


FIGURE 37-1 Components of Melker cricothyrotomy kit.

Procedure (for Melker Emergency Cricothyrotomy Kit) (Figs. 37-2–37-6)

- Grasp larynx firmly, holding it immobile with thumb and long finger; identify the CTM with the tip of the index finger
- Puncture CTM with thin-walled needle attached to a syringe containing saline or water, aiming 45° to caudad
- Aspirate air bubbles to confirm needle in airway
- Thread wire through needle
- Remove needle
- Use scalpel to enlarge opening around wire (some authors recommend preceding needle cannulation of CTM with a 1 cm, vertical incision, to facilitate dilator passage)
- Pass dilator/airway over wire into airway
- Remove dilator, inflate cuff of tracheostomy tube
- Attach breathing circuit to cricothyrotomy tube, begin ventilation
- Confirm with $ETCO_2$, breath sounds, chest rise
- Tie or suture the tube in place

Practicality

- Inexpensive (retails for $139.00 US per kit)
- Portable
- Unfamiliar and complex: requires training and practice
- "Final common pathway" for lifesaving ventilation when all else fails

Indications

- Facial, head, or neck trauma, where other means of intubation are precluded or impractical
- Inaccessibility of oral cavity (if nasal route is not practical)
- Failure to intubate or ventilate by other methods
- Severe upper airway obstruction that precludes use of a supraglottic airway

Contraindications

- Unrecognizable anatomic landmarks
- Child less than 8 years of age (formal tracheostomy is preferred)
- Coagulopathy (relative)
- Laryngeal fracture/trauma
- Lack of familiarity with the technique
- Laryngeal pathology (stenosis, cancer, infection)

Complications

- Bleeding
- Infection
- Endotracheal tube misplacement with failed ventilation
- Laryngeal trauma
- Esophageal perforation
- Posterior tracheal wall mucosal injury/perforation
- Subcutaneous emphysema
- Pneumothorax
- Subglottic stenosis
- Voice change, vocal cord injury
- Tracheoesophageal fistula



FIGURE 37-2 Needle puncture through the CTM.



FIGURE 37-3 After the wire is introduced, the tracheal tube and dilator are threaded over the wire.



FIGURE 37-4 The opening in the CTM is enlarged with a scalpel.



FIGURE 37-5 The airway and dilator are advanced into the airway.



FIGURE 37-6 The dilator is now removed with the wire, and ventilation can begin after position of the tracheal tube in the airway is confirmed.

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CHAPTER 38

Tracheostomy

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Concept

Critically ill patients often require prolonged ventilator support that is facilitated by tracheostomy, one of the most common surgical procedures, to replace endotracheal intubation.[1] Tracheostomy can be performed at the bedside or in the operating room (OR). It can be performed open or percutaneously. The open surgical tracheostomy was first described in 1909 by Chevalier Jackson. In recent years, the number of tracheostomies performed has increased by nearly 200%[2]; however, there is significant variability in the timing and frequency of tracheostomy.[3] Although the need for prolonged ventilator support and better access for suctioning the airway are the most common indications for tracheostomy, other indications include upper airway obstruction, severe facial and laryngeal trauma, radical oropharyngeal or thyroid surgery for advanced cancer, and neurologic disorders with inability to protect one's airway. Patient comfort and facilitating nursing care of the airway may also play a role.

The classic open technique involves a horizontal incision approximately 2 cm above the sternal notch or a vertical incision extending from the inferior edge of the cricoid cartilage toward the suprasternal notch. The dissection is carried down to the trachea as described below and a tracheostomy tube is usually inserted between the second and third tracheal rings. It has also become common to perform tracheostomy percutaneously in the critically ill patient for prolonged ventilatory support.

Evidence

There are many indications for tracheostomy, but the primary rationale behind performing tracheostomy is to facilitate prolonged ventilatory support in patients who fail to wean from the ventilator.[4] There is much controversy and conflicting evidence regarding the appropriate timing of a tracheostomy. Potential advantages of early tracheostomy include decreased ventilator days, decreased length of stay in the intensive care unit (ICU), and decreased ventilator-associated pneumonia. Studies have shown that in patients with inadequate reserve, tracheostomy decreases work of breathing.[5] Rumbak et al[6] found in a prospective randomized trial that performing tracheostomy within 2 days of admission to ICU was associated with a reduced occurrence of pneumonia, fewer days on the ventilator, a 50% reduction in the 30-day mortality rate, and a shortened ICU stay compared with tracheotomies performed at 2 weeks. A meta-analysis of 5 clinical trials performed with a total of 406 patients comparing early tracheostomy, defined as within 7 days, versus late tracheostomy in ICU patients showed that mortality and pneumonia rates were similar in both groups. However, early tracheostomy significantly decreased ICU length of stay and days on mechanical ventilation.[7] A recent practice management guideline for trauma patients recommended that early tracheostomy (within 3 to 7 days of admission) should be performed in patients with severe traumatic brain injury and in patients who are likely to require mechanical ventilation for more than 7 days.[8]

Despite the potential advantages of tracheostomy, as in any surgical procedure, there are well-documented complications that one must consider. In a meta-analysis of 1,212 patients, some of the more common complications included bleeding (5.7%) and infection (6.6%).[9] Other complications included pneumothorax, subcutaneous emphysema, and esophageal perforation. One of the most feared acute complications is accidental intraoperative or postoperative decannulation with the inability to intubate the trachea via the oral route or recannulate the trachea secondary to an immature fistula tract. Long-term complications include tracheal stenosis, tracheoesophageal fistula, and trachea-innominate fistula. Notwithstanding these potential complications, the overall benefit of tracheostomy usually outweighs the risk of the procedure.

Preparation

- Prepare instruments: a standard tracheostomy set may include a no. 11 or no. 15 scalpel blade, self-retaining retractors, tracheal spreader and tracheal hook, nos. 6–8 tracheostomy tubes, 10 cc syringe.
- General anesthesia is preferred for tracheostomy; however, local anesthesia with sedation is possible as well, particularly if the airway is tenuous and induction of general anesthesia presents an undue risk to the patient.

Procedure (Figs. 38-1–38-8)

- The patient is placed in a supine position with folded sheets or a roll under the shoulders extending the neck for better exposure (Fig. 38-1). Sometimes this may not be feasible secondary to neck injury or strict cervical spine precautions
- After infiltration of the subcutaneous tissues with local anesthetic solution (Fig. 38-2), a horizontal skin incision is made approximately 2 cm above the sternal notch (Fig. 38-3). Alternatively, a vertical incision can be made from the base of the cricoid approximately 3 to 4 cm caudally, though this may be less cosmetic. The incision is then carried through the subcutaneous tissue and platysma (Fig. 38-4). It is key to obtain hemostasis with electrocautery
- The strap muscles are identified and separated by making a vertical incision in the midline. The strap muscles may be divided if necessary (Fig. 38-5)
- At this point, one frequently encounters the thyroid gland. The isthmus can be divided by a serial clamping, tying, and dividing technique or by cautery to expose the trachea. In some cases, the thyroid isthmus may be retracted superiorly
- Once the trachea is exposed, the cricoid cartilage and the first 2 to 3 tracheal rings are identified. The tracheal hook can be inserted around the cricoid cartilage and retracted superiorly to help expose the second and third tracheal rings
- Prior to opening the airway, the inhaled gas mixture should be converted to air/oxygen with an FiO_2 as low as clinically feasible to avoid the risk of an airway fire
- Using a no. 11 or no. 15 scalpel blade, the membrane portion between the second and third tracheal rings is incised in a transverse fashion. Some prefer a vertical incision that can be extended through the second or third tracheal ring. Alternatively, a U-shaped incision can be made on three sides creating a flap inferiorly, which can be secured to the subcutaneous tissue using an absorbable suture
- Two sutures can also be placed on either side of the incision as stay sutures (Fig. 38-6). These can be taped to the neck or chest in case the tracheostomy becomes dislodged in the perioperative period
- The tracheostomy tube should be lubricated and the balloon checked prior to opening the trachea
- Once the trachea is opened, the incision is dilated using a tracheal spreader (Fig. 38-7). The endotracheal tube is pulled back to just proximal to the opening (never taking the tube out completely until the tracheostomy is placed). The tracheostomy tube is advanced into the airway
- The ventilator can then be connected to the new tracheostomy tube (Fig. 38-8) and end-tidal carbon dioxide level can be checked (if available) and the chest auscultated. Airway pressures and tidal volumes on the ventilator can also be checked. Once the tracheostomy position is confirmed, the endotracheal tube can be removed
- Some re-approximate the platysma and subcutaneous tissue on either side of the tracheostomy with sutures. Similarly, the skin can be loosely re-approximated. The tracheostomy tube is sutured to the skin on both sides. A tracheostomy tie is placed around the neck to further secure the tracheostomy tube

Practicality

- Generally requires transport to OR for critically ill patients: difficult logistics
- Expensive, primarily due to need for OR time and personnel
- Requires extensive surgical expertise
- Time-intensive: Generally not used in an airway emergency

Indications

- Prolonged ventilator support
- Improvement in pulmonary toilet
- Upper airway obstruction
- Severe airway or facial trauma
- Extensive head/neck surgery for cancer
- Risk of aspiration due to swallowing dysfunction

Contraindications

- Emergent situation with progressive hypoxemia
- Lack of familiarity or facility with technique
- Distorted or unrecognizable landmarks (relative)
- Coagulopathy (relative)

Complications

- Bleeding
- Infection
- Extraluminal placement of tracheostomy tube
- Decannulation with loss of airway
- Pneumothorax
- Subcutaneous emphysema
- Tracheal stenosis
- Tracheoesophageal fistula
- Tracheo-innominate artery fistula

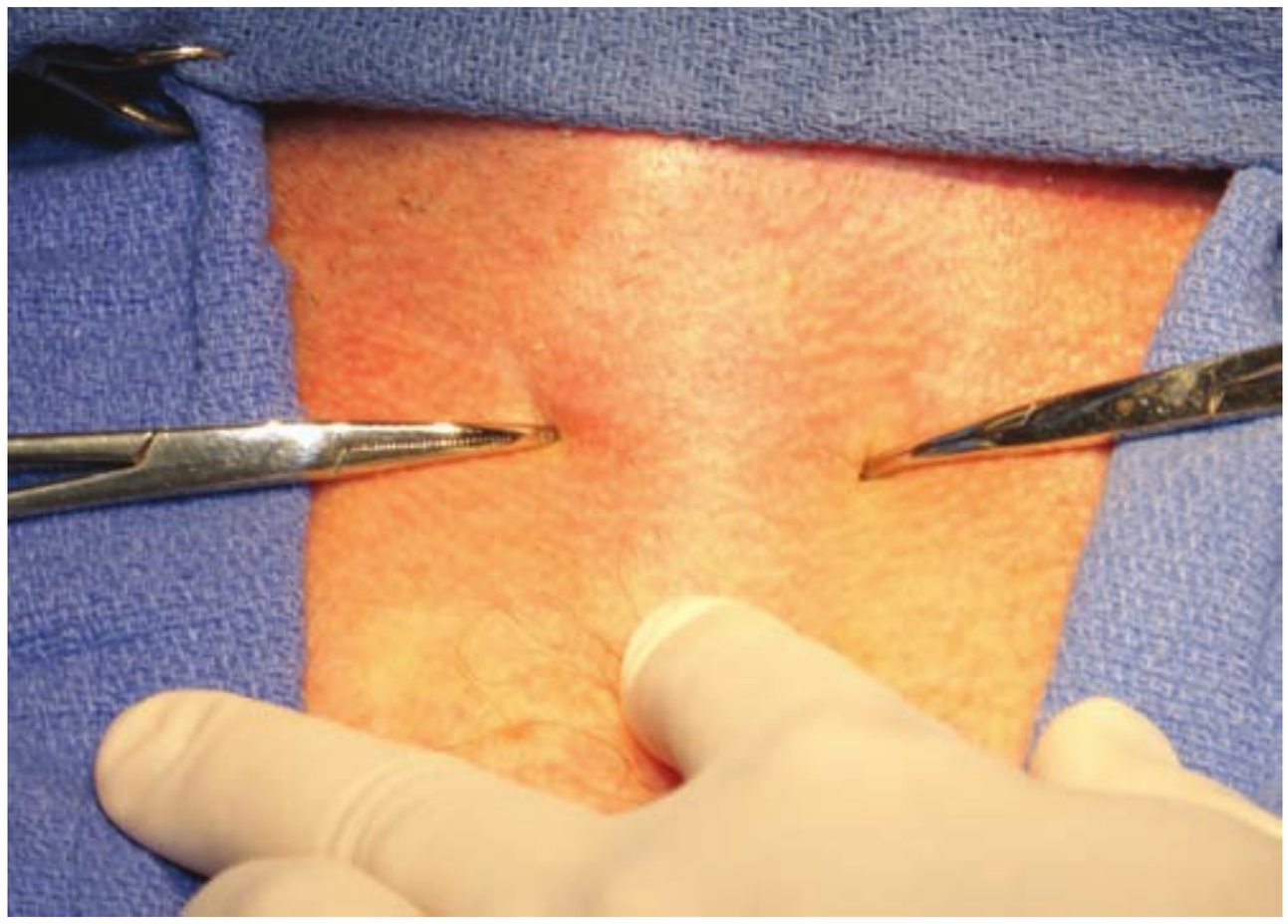


FIGURE 38-1 Landmarks: The index finger is on the sternal notch, head superior, and the planned incision is between the two hemostats.

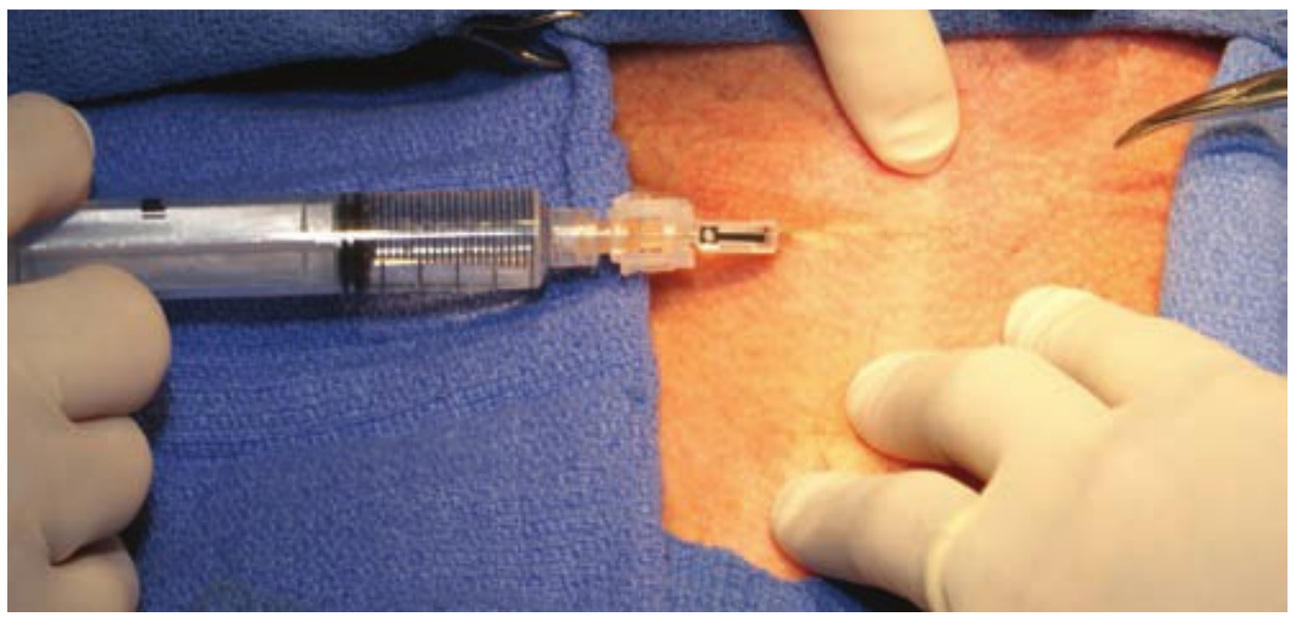


FIGURE 38-2 Local anesthetic is infiltrated under the skin along the planned incision.

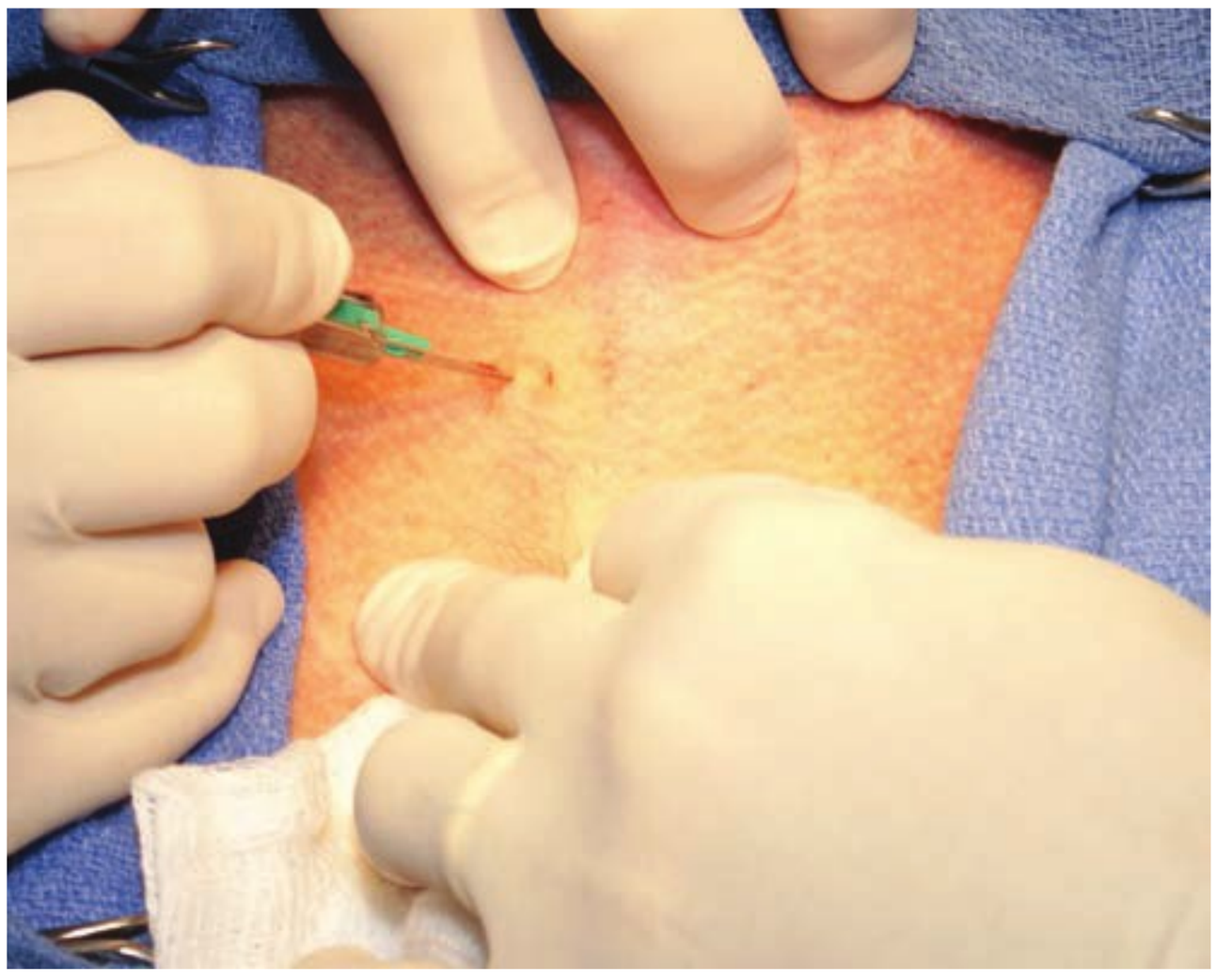


FIGURE 38-3 Transverse incision is made with the thyroid cartilage held in midline.

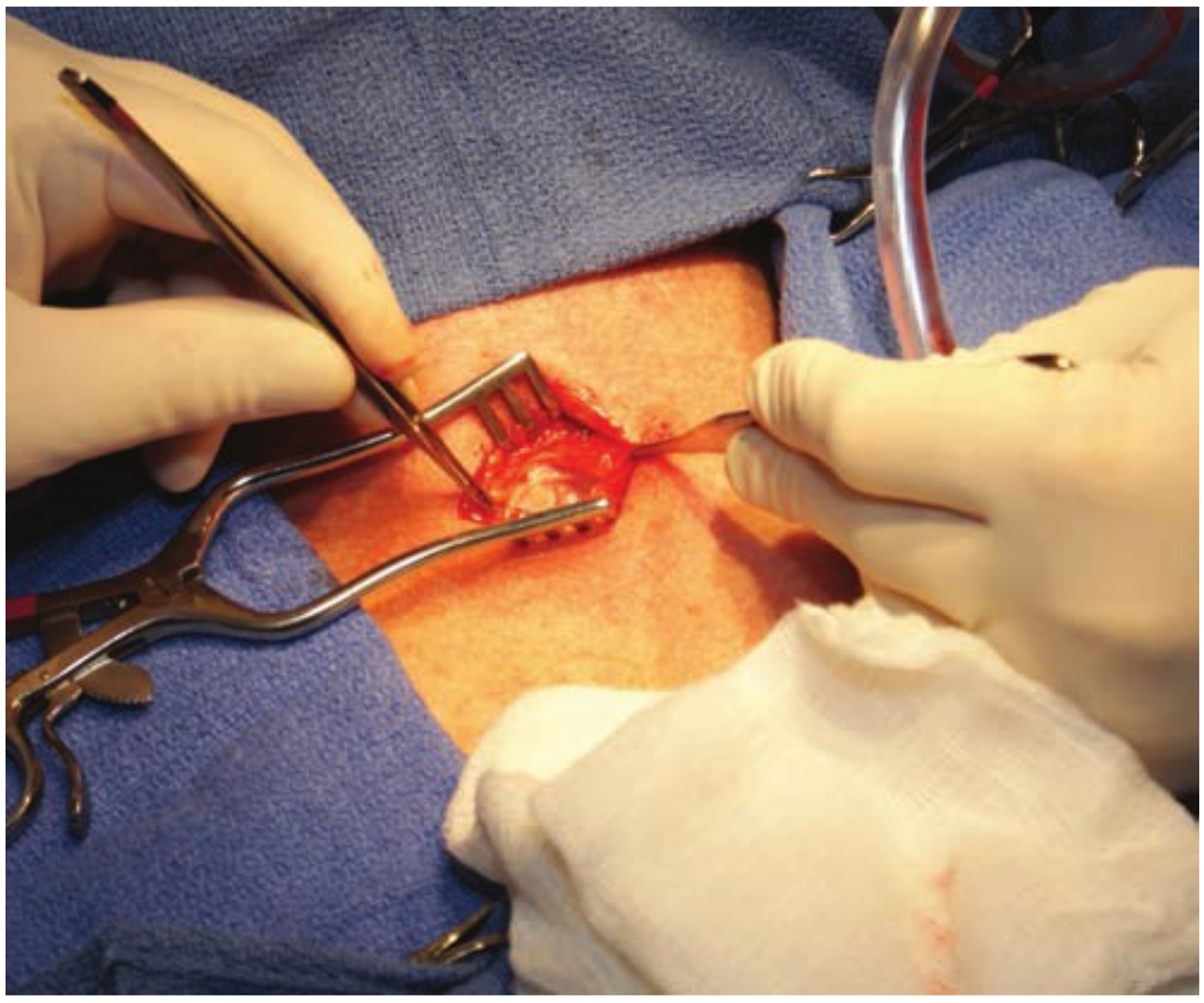


FIGURE 38-4 The subcutaneous tissue and platysma are dissected using electrocautery, and a self-retaining retractor is placed for better visualization.

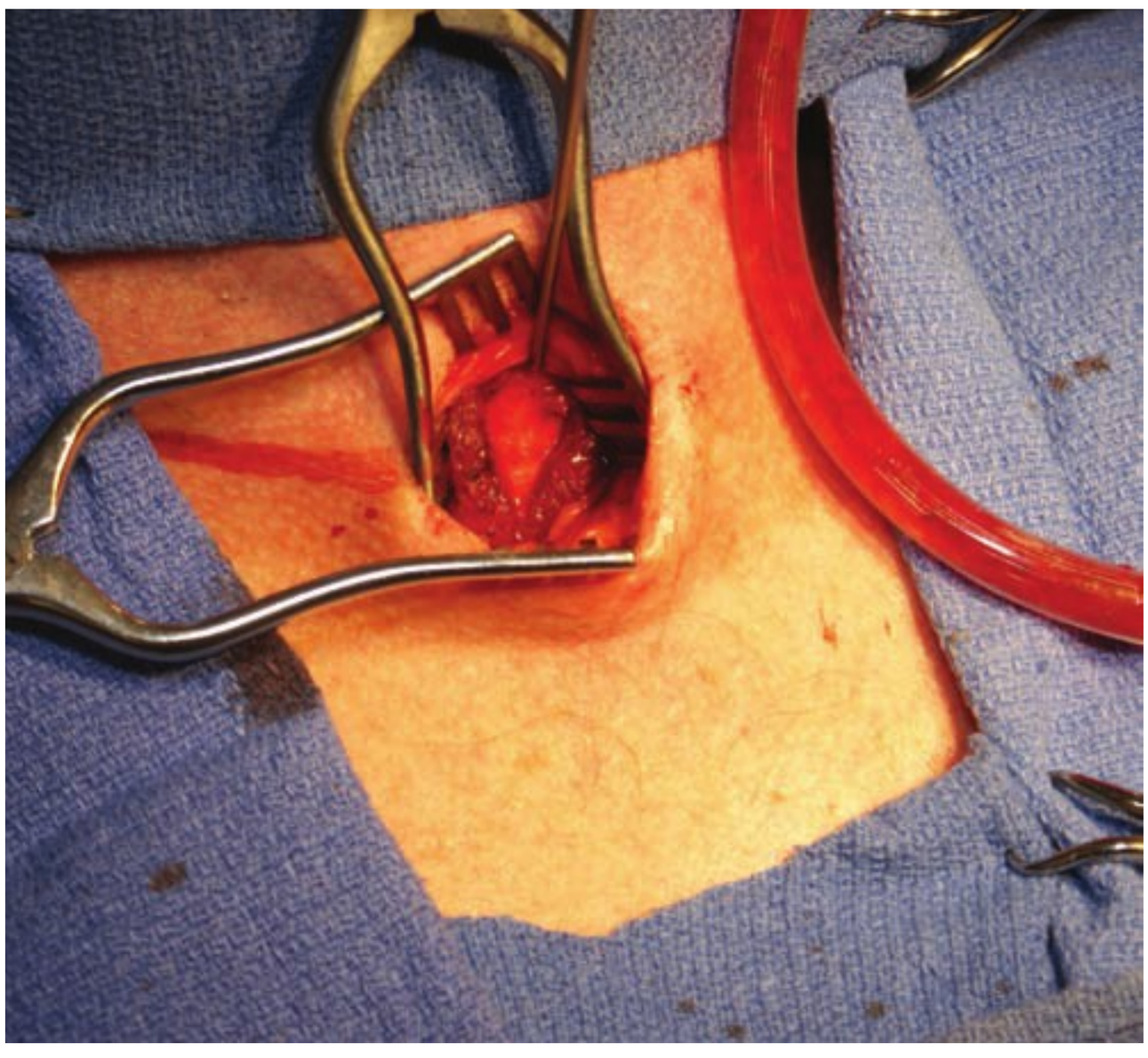


FIGURE 38-5 The platysma is divided and the strap muscles are separated in the midline.

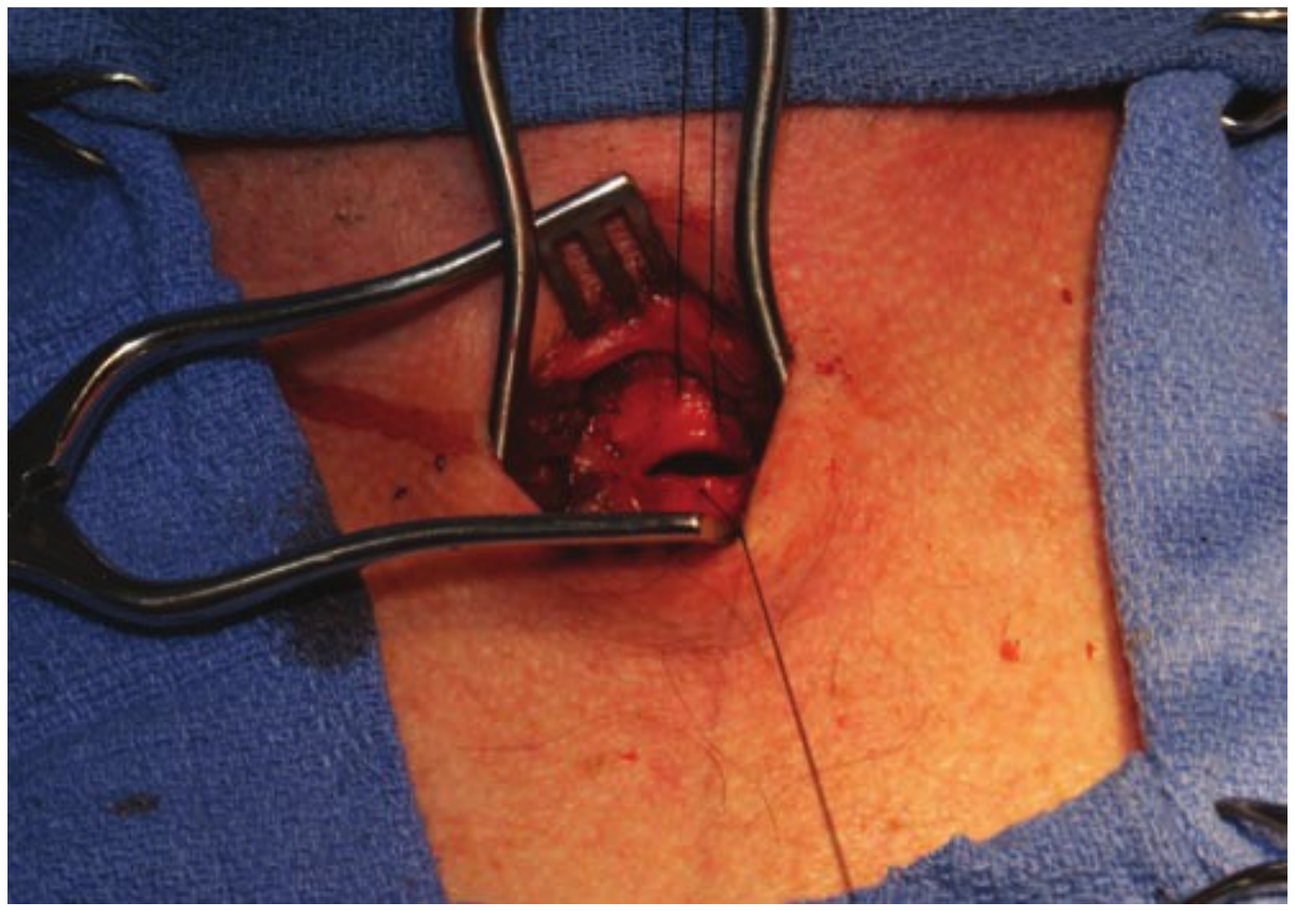


FIGURE 38-6 Stay sutures are placed superiorly and inferiorly (as demonstrated here), or laterally, to the planned tracheal incision for aid in retraction and as a safety mechanism in case the tracheostomy becomes dislodged in the perioperative period.

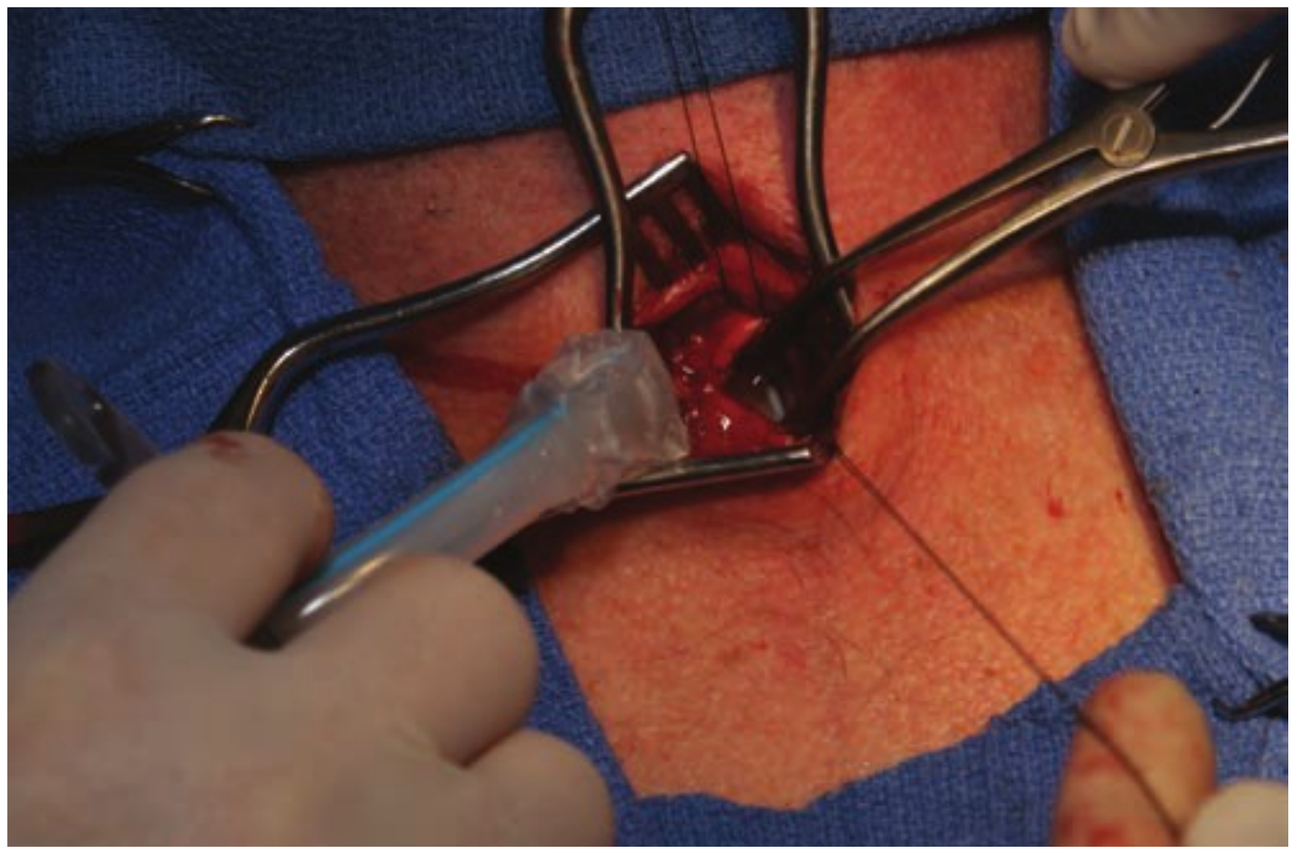


FIGURE 38-7 Tracheal spreader is used to dilate the trachea in the direction of the incision. The endotracheal tube can be visualized as it is pulled back to just above the incision to allow insertion of the tracheostomy. It should not be completely removed until the tracheostomy is in place.

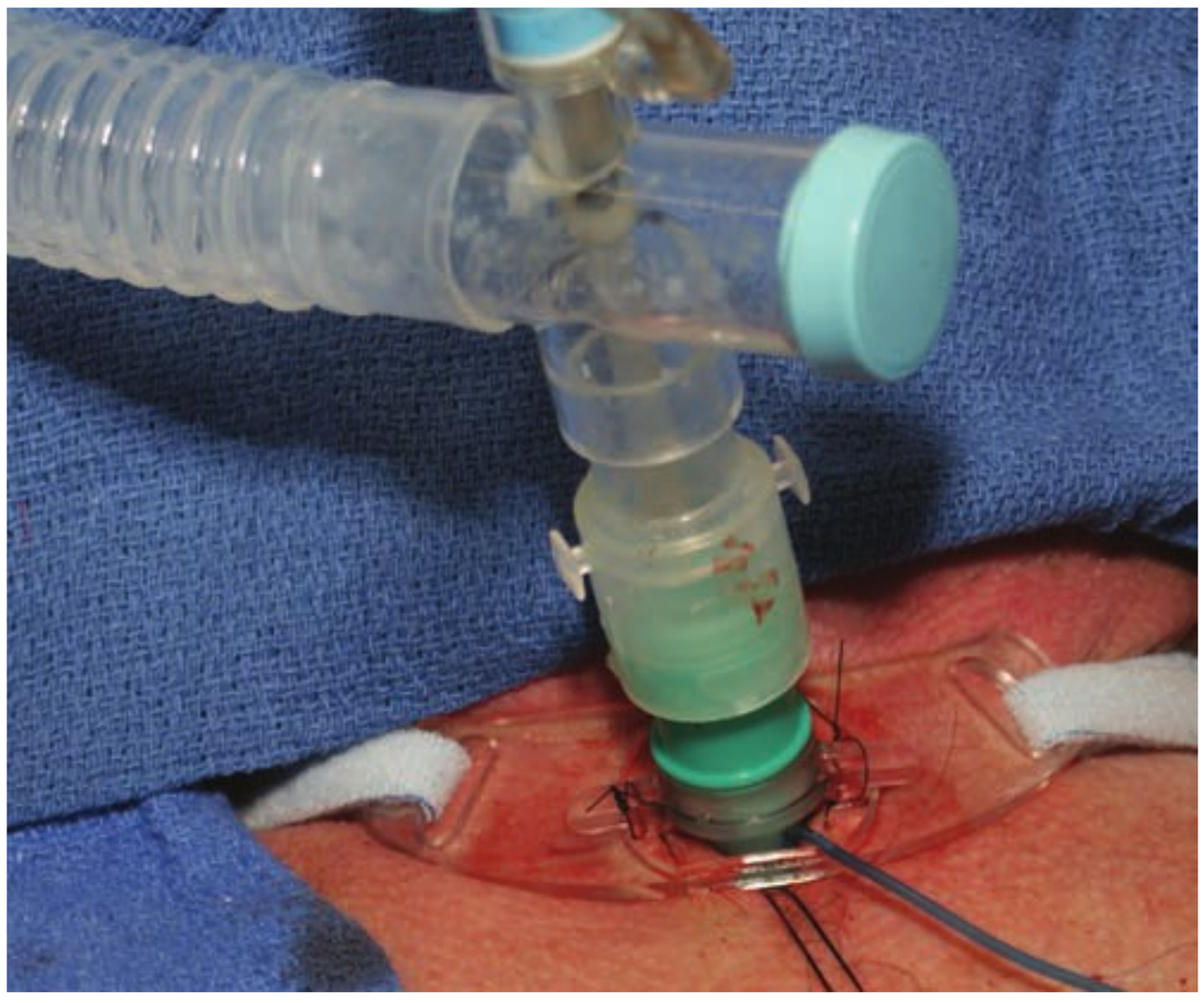


FIGURE 38-8 The tracheal cuff is insufflated and the tracheostomy is connected to the ventilator. The tube is then secured to the skin and the stay sutures secured to the patient's chest.

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CHAPTER 39

Percutaneous Tracheostomy

Spencer Nabors and David Crippen

Concept

Tracheostomy, as a procedure for producing secure airway access, has been performed and refined for over 4,000 years. Although historically challenged with frequent complications, advances in technology and minimally invasive techniques have made percutaneous tracheostomy (PCT) a popular procedure in many intensive care units (ICUs). PCT is a less invasive method for performing tracheostomy at the bedside that has become a practical alternative to standard open tracheostomy in recent years for critically ill patients requiring prolonged mechanical ventilation.

Tracheostomy for patients who cannot be weaned from mechanical ventilation has four major benefits:

- Increased patient comfort
- Improved pulmonary toileting
- Elimination of up to 150 cc of airway dead space
- The ability to wean off and put on mechanical ventilation without having to reintubate endotracheally

Soon after Seldinger described other needle over wire techniques in 1953, percutaneous tracheal access was described in 1955 by Shelden.[1] Unfortunately, this first approach of gaining access by guiding a cutting trocar into the trachea with the use of a slotted needle resulted in unacceptably high complications, as the technique for assuring a continuous airway during the procedure was not technically adequate. Since that time, the technique has been substantially refined. In 1969, Toye and Weinsten[2] described a technique using a recessed blade and single tapered dilator advanced into trachea over guiding catheter. Then, in 1985, Ciaglia et al[3] described the first completely percutaneous technique for PDT, using the Seldinger guidewire exchange technique followed by serial dilations with sequentially larger dilators. Later, in 2000, Byhahn et al[4] described the Ciaglia Blue Rhino, a modified Ciaglia technique using a single step dilation with a hydrophilically coated curved dilator. These methods, in their original form or in various hybrid forms, have proven to be convenient and effective alternatives to traditional open surgical tracheostomy and remain the most common method in use for PCT.

In both Europe and the United States, PCT has become quite popular. In a survey in Germany, Kluge et al[5] found that 86% of ICUs routinely perform PCT; 93% were performed at the bedside by intensivists. Although other variations have been described, the Ciaglia-based techniques have remained most prevalent, and when combined with bronchoscopic guidance, have been shown to be safe and efficacious in the hands of nonsurgeons, primarily intensivists.[6]

PCT improves health delivery efficiency and clinical outcomes. Most importantly, early evidence suggests that PCT reduces inherent risks and operational costs involved in transporting critically ill patients to the operating room (OR), avoiding expensive OR and anesthesia time.

Most of the patients for whom PCT is used are those in ICUs who are slow to wean from mechanical ventilators. Because such patients have already had an endotracheal tube (ETT) placed, active airway management for this procedure is not required, though sedation and assurance of airway patency during the procedure are necessary. Some authors have described the replacement of the ETT with a laryngeal mask airway for ventilation during this procedure, in order to improve visualization of tracheal structures,[7] though most PCTs are performed with the ETT still in place.

Evidence

Long-term complications related to classic tracheostomy appear to be reduced with this technique. However, as with any surgical procedure, acute complications may still occur, and the critical care physician or anesthesiologist taking care of ICU patients must be aware of these.[8]

Trottier[9] evaluated PCT performance prospectively in a cohort of patients in a medical-surgical ICU, and described a 12.5% incidence of posterior tracheal perforation with subsequent development of tension pneumothorax. Other authors have suggested that this is a rare complication.[10,11] Wise et al[12] reported the results of a survey sent to both trainees and established anesthesiologists in the United Kingdom. Acute complications described by this population included pneumothorax, hemorrhage, and loss of the airway or misplacement of the tracheostomy tube. However, a meta-analysis of studies comparing the open and percutaneous techniques described a lower frequency of postoperative bleeding and overall postoperative complications, as well as a

comparable frequency of overall procedural complications.[10] More recently, Higgins and Puthakee[11] conducted a meta-analysis of trials comparing the open tracheostomy technique with PCT and reported no difference in overall complications; there was a trend toward fewer complications with PCT, including fewer wound infections and episodes of unfavorable scarring. However, PCT appears to increase the risk of both extraluminal placement of the tube and inability to recannulate the airway if decannulation occurs. Diaz-Reganon et al[13] described an incidence of early postprocedural complications of 0.8% and late postprocedural complications of 1.1% with this procedure.

PCT can be performed by experienced operators without bronchoscopic guidance.[14] This procedure can be safely carried out on patients with coagulopathy or thrombocytopenia,[15] in patients with cervical fractures,[16] and obese patients.[17] A chest X-ray is not necessarily required after an uncomplicated PCT procedure.[18]

Preparation (Fig. 39-1)

- Appropriate monitoring must be ongoing during the procedure, as well as effective ventilation and preoxygenation with the ventilator, or with a resuscitation bag
- The patient should be positioned with maximal extension of the neck, if this is not contraindicated
- Open the standard kit and inspect the contents (Fig. 39-1). The operator should be familiar with each part of the kit and its corresponding purpose. Fill the wells of the kit with normal saline for lubrication and flush material
- Tracheostomy tube should be fitted over the appropriate sized introducer, which should be lubricated
- Bronchoscopy (optional) is performed via the indwelling ETT, with attention to peak inspiratory pressures, which will rise substantially when the insertion cord of the scope is placed inside the breathing circuit. The tip of the scope should not protrude past the end of the ETT, to avoid damage to it

Procedure (Figs. 39-2–39-11)

- Disinfect the skin and apply local anesthesia
- A 3 cm, transverse incision is made through the skin over the upper trachea, followed by blunt dissection through soft tissue (Fig. 39-2), and the region between the first and second or second and third tracheal rings is located[19]
- The introducer needle, with syringe attached, is then placed through the trachea between rings 1 and 2, or between rings 2 and 3, aspirating as you advance the needle (Fig. 39-3). Free air should be aspirated from the needle when the trachea is entered; the bronchoscope can be used to confirm intratracheal needle placement.[19] Disconnect the needle in order to insert the guidewire. The guidewire

FIGURE 39-1 Equipment for PCT.





FIGURE 39-2 After transverse skin incision, blunt dissection is carried out down to the level of the trachea.



FIGURE 39-3 Needle placement in the trachea, with air aspiration to confirm.

is then placed through the needle and should remain freely mobile. Withdraw the needle while holding the guidewire in place (Fig. 39-4). A bronchoscope can be used to observe the entry of the wire and dilators into the trachea (Fig. 39-5)

- The entry hole into the trachea is now dilated by sliding a hydrophilically coated 14G dilator (or series of sequentially larger dilators) over the wire (Fig. 39-6). The white stylet guide and the 14G dilator (or the largest of the set of sequentially larger dilators) are placed in one piece over the wire (Fig. 39-7). A round "stop" on the white guide keeps the dilator from overshooting it (Fig. 39-8). Once dilated, the hydrophilically coated dilator comes off, leaving the white guide over the wire (Fig. 39-9)
- Next, the tracheal tube, fitted on the introducer, should be advanced over the guidewire and stylet into the trachea (Fig. 39-10)
- The guidewire, white stylet guide, and introducer are removed (Fig. 39-11). The cuff of the tracheal tube is inflated and the ventilation circuit immediately attached
- Confirmation of ventilation by the usual means is carried out, and, once confirmed, the ETT can be removed from the mouth
- The tracheal tube is fixed in place with tapes or sutures



FIGURE 39-4 The guidewire has been placed through the needle into the trachea of a cadaver specimen.



FIGURE 39-5 Bronchoscopic guidance of PCT during training in the anatomy lab. Here the wire is seen within the tracheal lumen.



FIGURE 39-6 The white style guide, placed over the wire, is shown in this bronchoscopic view of the airway.

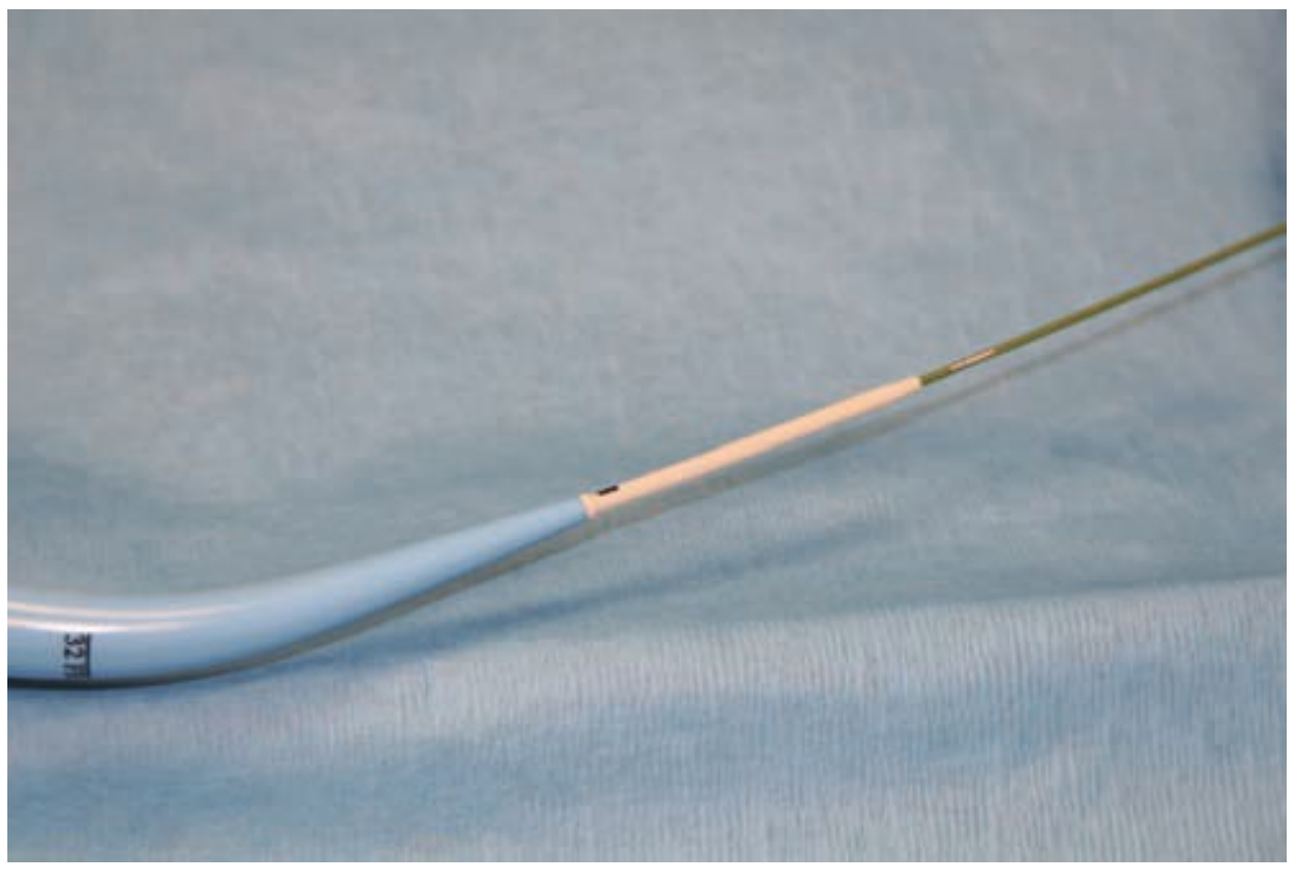


FIGURE 39-7 The white stylet guide and dilator are in place over the wire

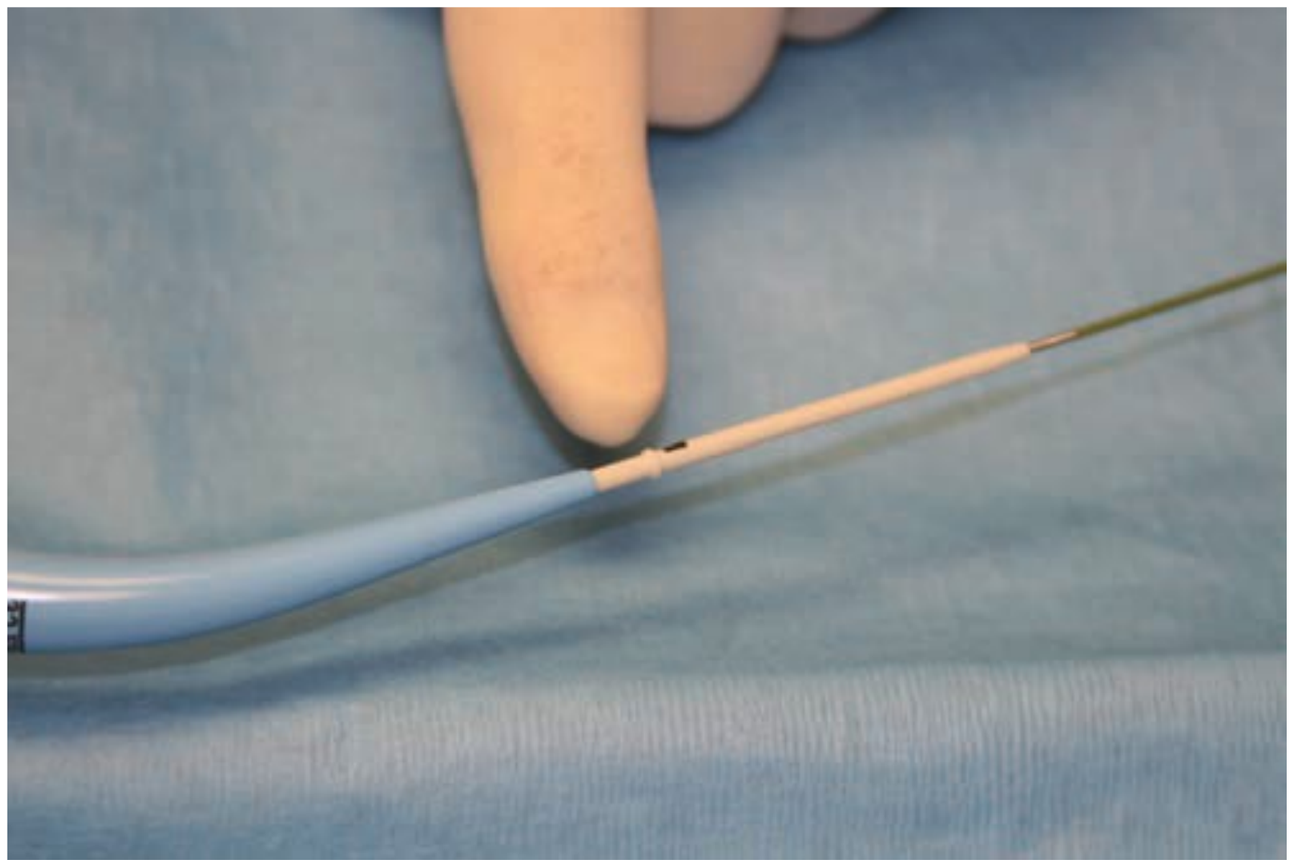


FIGURE 39-8 The round "stop" on the white guide to prevent insertion of the dilator too far.



FIGURE 39-9 The white guide in place over the wire after removal of the dilator, ready to guide insertion of the introducer and the tracheal tube.



FIGURE 39-10 Bronchscopic view of insertion of the tracheostomy tube and dilator over the wire and guide into the trachea.



FIGURE 39-11 After removal of the dilator, guide catheter, and guidewire, the tracheal tube is ready for connection to the breathing circuit and for fixation with ties or sutures.

Practicality

- Relatively inexpensive compared with surgical tracheostomy
- Logistically favorable—no requirement for transport to OR
- Not simple: Requires training, practice, and familiarity with procedure as well as individual kits or components
- Requires significant time to perform—not useful as an emergency procedure for failed ventilation

Indications

- Expected prolonged intubation during mechanical ventilation (including but not limited to the following clinical situations)
- Airway obstruction
- Need for prolonged mechanical ventilation in cases of respiratory failure
- Need for improved pulmonary toilet
- Prophylaxis
- Severe sleep apnea not amenable to continuous positive airway pressure devices

Contraindications

- Age younger than 8
- Gross distortion of neck anatomy (pathology, infection, etc.)
- Hypercarbia or hypoxemia (these are likely to get worse during procedure)
- Elevated intracranial pressure
- Severe coagulopathy

Complications[19]

- Elevated airway pressures with the potential for barotraumas
- Hypoxemia during tracheal tube placement, when ventilation is briefly paused
- Puncture of ETT cuff with resultant difficulty in effective ventilation
- Bleeding
- Damage to bronchoscope
- Puncture or fracture of tracheal ring
- Perforation of back wall of trachea or esophageal puncture
- Persistent cuff leak from poor position or ill-fitted tracheostomy tube

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PART XI

Pediatrics

CHAPTER 40

Pediatric Airway Anatomy and Approach

Franklyn Cladis

INTRODUCTION

For the health care provider who is not experienced in in pediatrics, the pediatric airway can be challenging. The difficulty in airway management with this group of patients is primarily because of its differences from the adult airway. Understanding the anatomy and the physiology of the pediatric airway can help make this landscape less challenging. The objective of this chapter is to provide the essentials of pediatric airway anatomy and to provide a framework for examining this patient population.

DEVELOPMENTAL ANATOMY

Understanding the differences between the pediatric and the adult airway makes the management of these patients less challenging and safer. These differences refer to the comparison between the neonatal airway and the adult airway. The toddler's airway is a transition zone between the neonatal and adult. The most significant differences include the size of the pediatric head, size of the tongue, position of the larynx, and shape of the epiglottis. The narrowest portion of the pediatric airway is controversial but has historically been assigned to the cricoid ring.

1. Head size—The neonate and infant heads are relatively larger than the adult head. Because of the size of the occiput, when the neonate or infant is placed supine the neck assumes a flexed position (Fig. 40-1A,B). They do not require any additional support behind the head to assume the "sniffing" position. In fact, they may need a small shoulder roll to help extend the head out of the flexed position and into the conventional "sniffing" position.
2. Tongue—The tongue is relatively large in the neonate and infant compared with the adult. This may be a factor in airway obstruction in the anesthetized pediatric patient. During anesthesia, the musculature of the oral cavity including the tongue is relaxed and the tongue may lie against the soft palate preventing oral ventilation.[1] Continuous positive airway pressure, jaw thrust, and an oral airway will often relieve this obstruction. More recent evidence suggests that the tongue may not be the most common cause of airway obstruction. In an ultrasound study by Abernethy,[2] the tongue did not change position after the induction of anesthesia, and the authors concluded that it might not play a significant role in airway obstruction. In addition, Mathru and others[3] in adults and Litman and others[4] in children demonstrated in MRI studies that the most significant narrowing and most likely site of upper airway obstruction during sedation is at the soft palate and the epiglottis.
3. Position of larynx—The position of the larynx is classically described as being more cephalad in the newborn than the adult. Negus[5] described the location of the larynx at the middle of the third cervical vertebra in the preterm infant (C3), at the C3-4 interspace in the full term infant, and at the C4-5 interspace in the adult (Fig. 40-2). In an MRI study,[6] the position of the hyoid bone in 15 pediatric patients aged 0 to 2 years was located at second and third cervical vertebrae (C2-3) compared with the third and fourth cervical vertebrae (C3-4) in the adult. The cephalad location of the larynx may make the laryngoscopic view more challenging because the angle from the base of the tongue to the glottic opening is more acute. This has been one reason cited for the use of straight laryngoscope blades in pediatric patients, to facilitate this view.
4. Epiglottis—The size and the position of the epiglottis are different in the pediatric patient compared with the adult. The adult's epiglottis is typically more broad and rigid and is positioned more parallel to the trachea. The newborn epiglottis is thinner, omega shaped, and less rigid.[7] Lifting the epiglottis may be

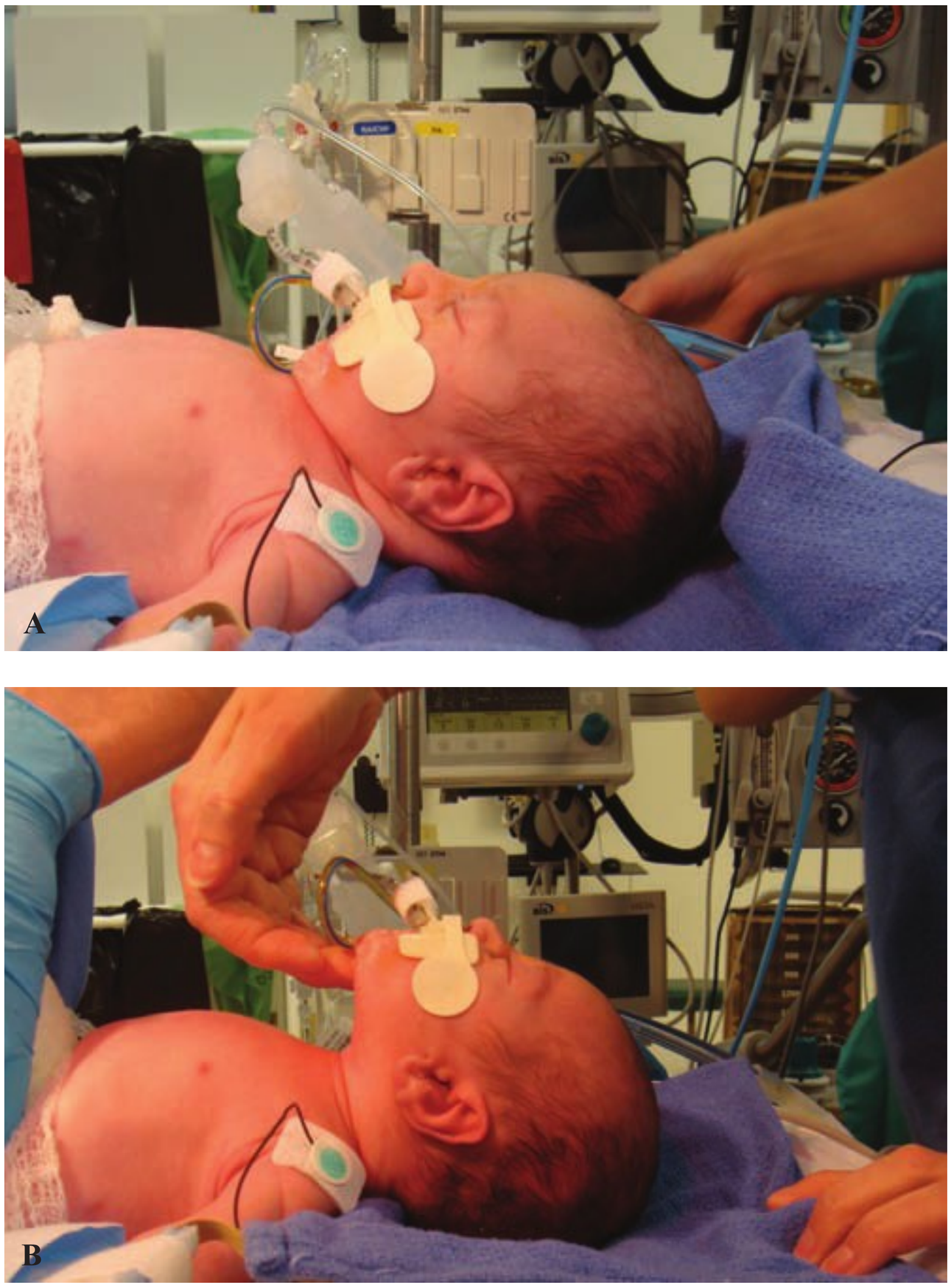


FIGURE 40-1 The large occiput in the neonate and infant places the neck in a natural flexion **(A)**. Gently extending the neck or placing a small shoulder roll will place the head in a "sniffing" position **(B)**. (Courtesy of Franklyn Cladis.)

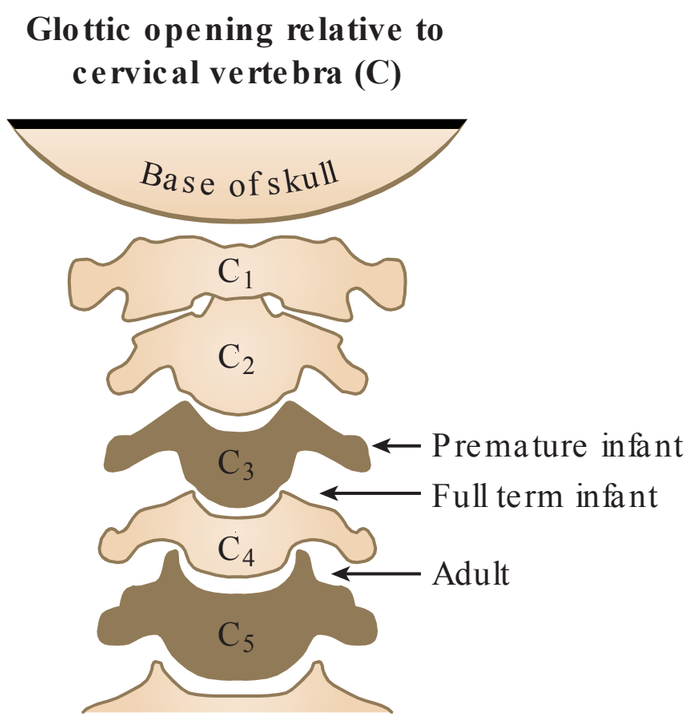


FIGURE 40-2 Position of larynx. The position of the larynx for the premature infant (7 months gestational age), full-term infant at birth, and adult. The four and half month fetus has its larynx positioned even more cephalad at C2. (From Eckenhoff JE. Some anatomic considerations of the infant larynx influencing endotracheal anesthesia. Anesthesiology. 1951;12:401–410, with permission.)

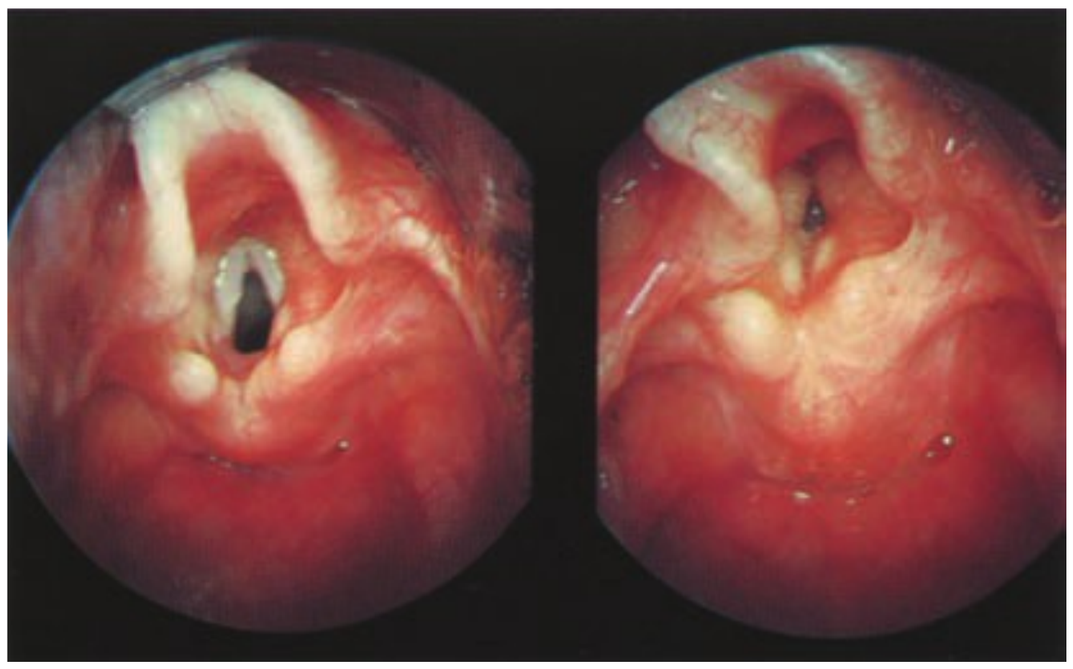


FIGURE 40-3 Larynx of an infant. Note the omega-shaped epiglottis.

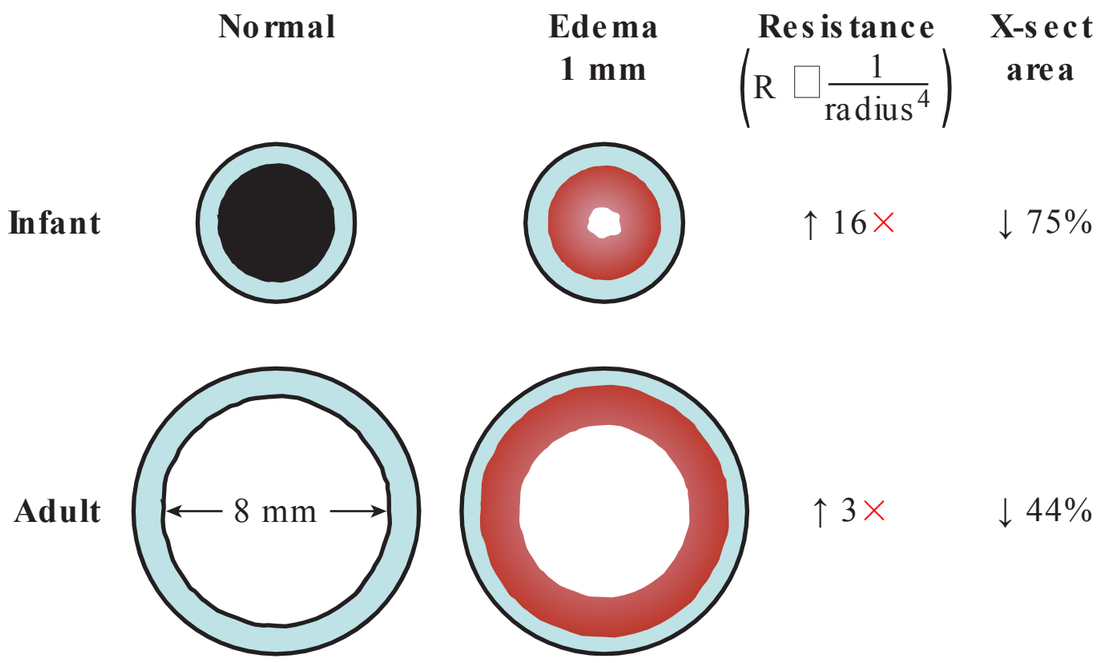


FIGURE 40-4 The effects of airway edema on the resistance in the infant and the adult. The infant's airway is significantly more compromised by a small change in airway diameter because of a larger increase in airway resistance and decrease in cross-sectional area. (From Cote CJ, Lerman J, Todres ID. A Practice of Anesthesia for Infants and Children. Saunders Elsevier; 2009, with permission.)

more difficult with a curved blade in the vallecula in the young child. Again, the straight blade may be more effective in the pediatric patient (Fig. 40-3).

5. Subglottis—The cricoid cartilage has been described as the narrowest part of the pediatric airway, compared with the glottic opening in the adult. Recently this has been challenged. Litman and others in 2002[8] found that the most constricted part of the larynx measured on MRI in a sedated spontaneously breathing pediatric patient is the glottic opening and the immediate subvocal cord level. Dalal and others[9] confirmed this when they measured the cross-sectional area of the airway with video bronchoscopy at the level of the glottis and the cricoid ring in anesthetized, paralyzed pediatric patients. They found that the glottis was the narrowest part of the airway in all age groups (6 months to 13 years) and that the airway was more cylindrical than funnel shaped. Both authors also found that the cricoid ring is slightly elliptical.

Although the glottic opening is the narrowest part of the larynx, it is more pliable than the rigid cricoid ring. Therefore, it is still important to recognize that the cricoid ring may still be "the functionally narrowest portion of the larynx"[10] and may be prone to subglottic edema and airway compromise. Because airway resistance (Fig. 40-4) is inversely related to the fourth power of the radius of the lumen, any subglottic edema results in a greater change in airway resistance in the infant than the adult.

DEVELOPMENTAL PHYSIOLOGY

Neonates and infants are obligate nasal breathers.[11,12] Infants are obligate nose breathers because of their anatomy. The soft palate can contact the epiglottis. In fact, when they feed they can lock the soft palate into the epiglottis and functionally separate their nasal breathing from their feeding.

Young children have high oral airway resistance when breathing through the mouth. However, Miller and his colleagues[13] demonstrated that breathing through the mouth does occur in preterm infants when the nasal passage is occluded. Oral breathing is inconsistent until infants are approximately 3 to 5 months old, but Miller demonstrated that 8% to 33% of preterm infants (31 to 36 weeks, respectively) will breathe through their mouth when the nose is occluded. The clinical significance is that although oral ventilation may occur before 3 to 5 months, it may also be more difficult if the infant's nasal passages are obstructed with a nasogastric tube or secretions.

Newborns and infants also have a higher metabolic rate and increased oxygen consumption. Neonatal oxygen consumption is 2 to 3 times greater than that of the adult (5 to 8 vs 2 to 3 mL/kg/min).[14] This is a significant cause for the rapid oxygen desaturation observed during apnea or hypoventilation.

PEDIATRIC AIRWAY EXAMINATION

The airway examination for the pediatric patient can be difficult because the patient may not be cooperative. An infant will not open his mouth, and the toddler will often hide his face. The essential features of an airway examination are outlined below.

1. History—A history of congenital or acquired pathologies (see Table 40-1) would suggest that a difficult airway may be present. Also a history of difficulty with ventilation or intubation with previous anesthetics should be noted.
2. Craniofacial structure—The face should be evaluated en-face (face to face) and in-profile. Attention should be paid to identifying syndromes (craniofacial anomalies, Down syndrome) (Fig. 40-5), facial asymmetry (Fig. 40-6), and retrognathia (Fig. 40-7). These features can be identified even in the uncooperative patient.
3. Intraoral—The intraoral examination can be very difficult to achieve in the infant or young toddler but can be facilitated by placing the child's head in the examiner's lap and gently using a tongue blade to look inside the mouth.
   a. Mouth opening—How wide the child can open his mouth should be assessed. While the mouth is open, investigate the presence of airway/tongue masses, a high arched palate or a cleft palate.
   b. Mallampati—The Mallampati classification was designed for adults and although it is not known to be reliable or valid in children, it is used in this population when they are cooperative.[15]
   c. Size of tonsils—Large tonsils may predict the presence of obstructive sleep apnea (OSA) and difficulty with mask ventilation or postoperative airway obstruction. Pediatric patients with severe OSA have reduced opioid requirements.[16] A grading system for tonsillar hypertrophy is presented in Fig. 40-8.

Table 40-1

Anatomic Pathology Predicting the Difficult Pediatric Airway (ventilation and/or intubation)

1. Choanal Atresia	CHARGE association, Apert Syndrome
2. Macroglossia	Down syndrome, Beckwith–Wiedemann syndrome, Hunter syndrome, Hurler syndrome
3. Midface hypoplasia	Apert syndrome, Crouzon syndrome, Pfeiffer syndrome, Carpenter syndrome, achondroplasia
4. Hemifacial microsomia (asymmetry)	Goldenhar syndrome
5. Retrognathia	Pierre Robin sequence, Treacher Collins syndrome, Cornelia de Lange syndrome, Smith-Lemli-Opitz syndrome
6. Decreased neck extension	Klippel–Feil sequence, cervical spine injury or fusion, burns or contractures
7. Airway or neck masses	Tumors, abscesses
8. Infiltrative disease	Hunter syndrome, Hurler syndrome
9. Subglottic stenosis	Croup, prolonged NICU intubation
10. Facial or orthodontic hardware	Midface distractor, mandibular distractor, nasal alveolar molding

Abbreviation: NICU, neonatal intensive care unit.

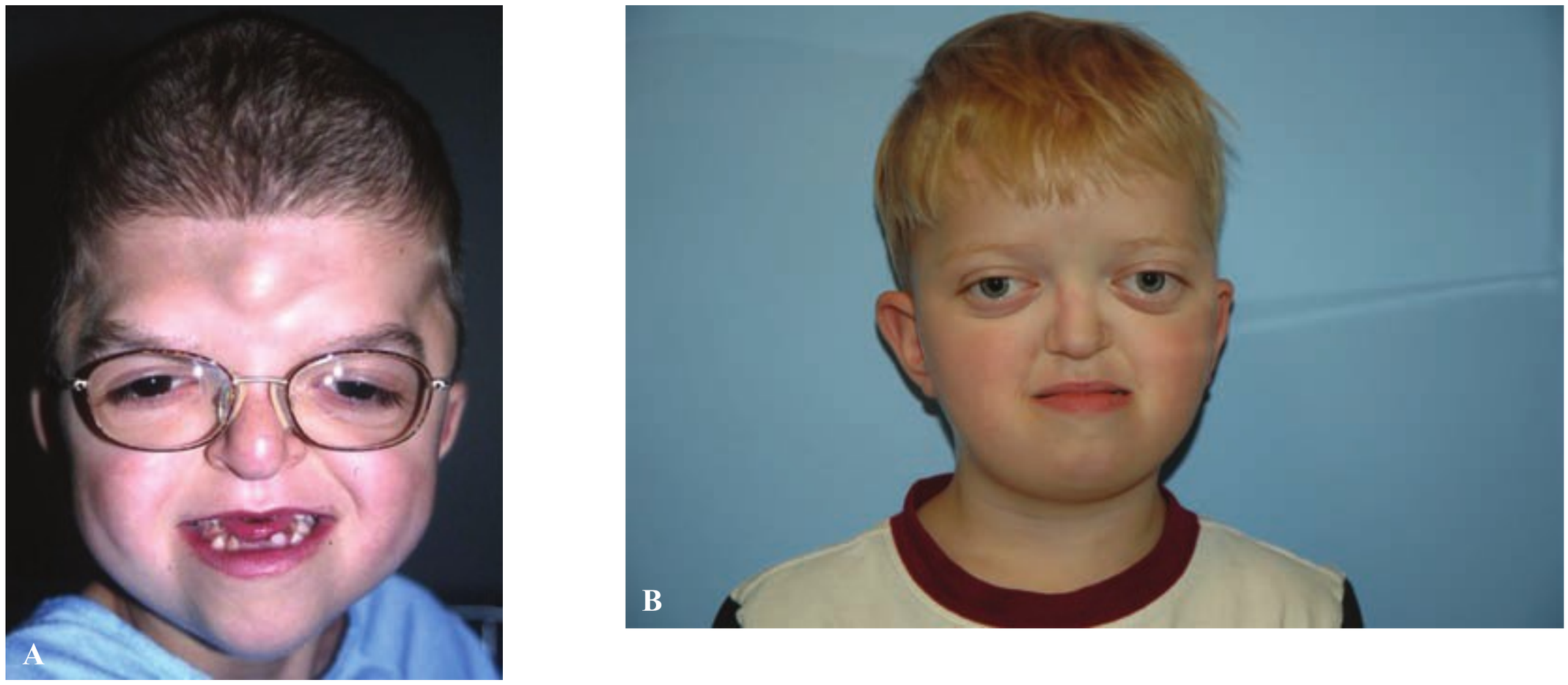


FIGURE 40-5 **A:** Apert syndrome—a frontal view of a child with Apert syndrome. Note the midface hypoplasia. Children with Apert syndrome also have hand anomalies. **B:** Crouzon syndrome—a frontal view of a child with Crouzon syndrome. Children with Crouzon syndrome generally do not have hand anomalies.
(Courtesy of Joseph Losee.)



FIGURE 40-6 Facial asymmetry. The patient has mandibular distractors in place. These will make mask ventilation more difficult.
(Courtesy of Joseph Losee.)

d. Dentition—Any loose, damaged, or missing teeth should be noted. If the tooth is significantly loose it may need to be removed prior to airway instrumentation. This can typically be performed after anesthesia has been induced.

4. Neck extension—Any limitations of neck extension should be noted (see Table 40-1). Children with Down syndrome may have atlantoaxial instability although normal preoperative neck radiographs will not predict which patients are at risk.

5. Airway sounds/Auscultation—Abnormal airway sounds can predict airway pathology. Inspiratory stridor indicates extrathoracic pathology (foreign body, laryngomalacia, subglottic stenosis, croup, epiglottitis) biphasic stridor indicates glottic pathology, and expiratory stridor or wheezing suggests intrathoracic pathology (tracheomalacia, foreign body). A hoarse voice or cry suggests vocal cord pathology (vocal cord palsy, vocal cord papillomas).



FIGURE 40-7 A lateral view of an infant with Pierre Robin Sequence. Note the hypoplastic mandible resulting in retrognathia. (Courtesy of Joseph Losee.)

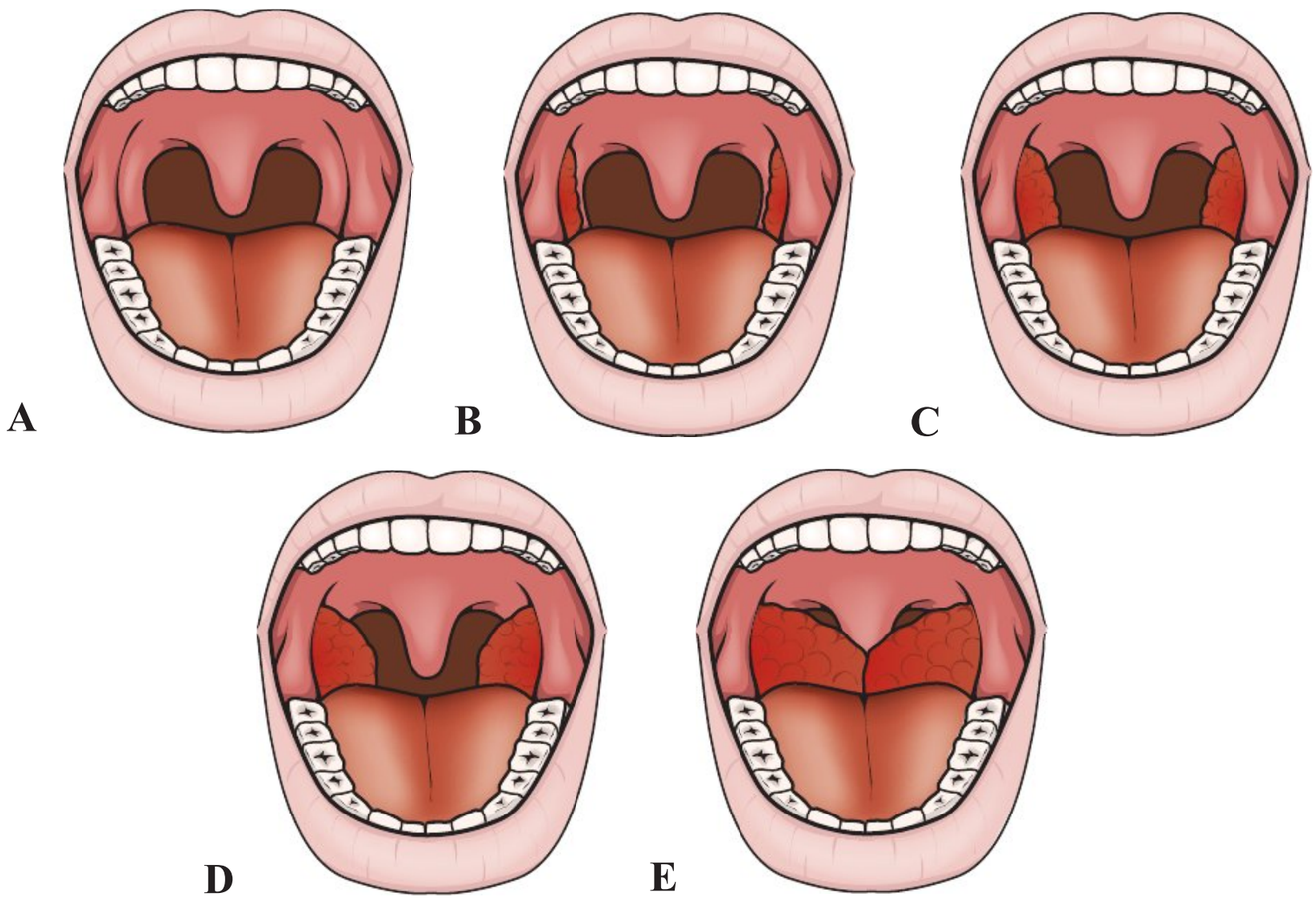


FIGURE 40-8 Tonsillar grading. Zero indicates a tonsillectomy **(A)**. Grade I tonsils are in the tonsillar fossa and are just seen behind the anterior pillars **(B)**. Grade II tonsils are visible behind the anterior pillars **(C)**. Grade III tonsils are three quarters of the way to the midline **(D)**. Grade IV tonsils completely obstruct the airway and are known as "kissing" tonsils **(E)**. (From Friedman M, Tanyeri H, La Rosa M, et al. Clinical predictors of obstructive sleep apnea. Laryngoscope. 1999;109:1901–1907, with permission.)

6. Radiography and endoscopy—CT imaging of head and neck may be very beneficial in defining the degree of airway compromise from airway tumors and abscesses. Previous endoscopies of the trachea can help define preexisting pathology like laryngomalacia, subglottic stenosis, and tracheomalacia.

CONCLUSION

The pediatric airway is different but *NOT* necessarily more difficult to manage than that of adults. However, pediatric patients have decreased reserve for the following reasons.

a. They may be more prone to airway obstruction from the relatively large tongue and head and highly compliant posterior pharynx and chest wall/trachea.
b. Proportionally larger pathologic changes occur and more respiratory compromise occurs with edema/inflammation of the airway.
c. Infants have increased oxygen consumption compared with adults.

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CHAPTER

41

Direct Laryngoscopy in Pediatrics

Jay B. Tuchman

Infants and children are not simply miniature adults, and their specialized anatomy and physiology significantly impact the basic approach to pediatric laryngoscopy. As with any endeavor, and particularly in management of the pediatric airway, preparation is the key to success. The heightened emphasis on adequate preparation for airway instrumentation stands in reverse proportion to the age of the patient. This focus may be attributed to a threefold increase in oxygen consumption, increased closing volumes, and consequently a predisposition to rapid oxygen desaturation. As such, multiple sizes of oropharyngeal and nasopharyngeal airways, laryngoscopy blades, and endotracheal tubes (ETTs) should always be immediately available (Fig. 41-1). Furthermore, when proceeding with induction through preexisting intravenous access, adequate preoxygenation is strongly advised to help mitigate desaturation during direct laryngoscopy.

Optimal positioning for direct laryngoscopy depends on the age of the patient and the position of the laryngoscopist (sitting vs standing). In children older than age 6, positioning is similar to adults in the classic "sniffing" position: elevation of the head 5 to 10 cm with a pillow beneath the occiput, extension of the head at the atlantooccipital joint, and alignment of the oral, pharyngeal, and tracheal axes to facilitate laryngeal visualization. Infants, however, due to their disproportionately large occiput, do not usually require elevation of the head to adequately achieve anterior displacement of the cervical spine and appropriate laryngeal visualization. Shoulder rolls for neonatal laryngoscopy are only beneficial when the practitioner is seated (the classic position of the otolaryngologist) and may actually hinder the standing practitioner (Fig. 41-2). A more beneficial position for standing neonatal intubation provides for an assistant holding the head in slight extension, the shoulders flat on the operating room table, with the patient placed at the level of the xiphoid process of the intubator.

After inhalational induction via mask and establishment of an intravenous route for medication, various pharmacologic approaches may be used to achieve appropriate conditions for direct laryngoscopy and intubation, both with and without muscle relaxation. Most infants and children without cardiovascular disease, requiring endotracheal intubation for airway protection during short surgical procedures, may be intubated without muscle relaxation, avoiding the potential adverse effects of these medications. Inhalational sevoflurane (6% to 8%) in oxygen is used with assisted and controlled ventilation until the child is motionless, apneic, and pupils are fixed, with careful attention to heart rate and blood pressure to avoid myocardial depression. Laryngoscopy can then be facilitated by propofol 1 to 2 mg/kg, and spraying of the vocal cords with 1 mg/kg of lidocaine (1% to 2%) via an atomizing device, after achieving adequate depth of anesthesia for intubation. For elective procedures during which muscle relaxation is indicated, intermediate acting nondepolarizing muscle relaxants such as rocuronium (0.3 to 0.5 mg/kg infant, 0.6 to 1.2 mg/kg children) or cisatracurium (0.1 to 0.2 mg/kg) are used to facilitate endotracheal intubation. For patients with a full stomach, requiring a rapid-sequence intubation, the dose of rocuronium may be increased to 1.2 mg/kg to achieve intubating conditions within 60 seconds in conjunction with an induction agent, such as propofol (2 to 4 mg/kg), thiopental (5 to 6 mg/kg), or ketamine (1 to 3 mg/kg). The FDA "black box" warning cautions against the use of succinylcholine for routine pediatric airway management, due to several case reports of hyperkalemic cardiac arrests in children with undiagnosed Duchenne muscular dystrophy (mortality 55%) (Fig. 41-3). As such, the use of succinylcholine in pediatric anesthesia is restricted to emergency intubations, or those situations where the airway must be immediately secured, such as laryngospasm, difficult airway, or full-stomach precautions. The routine administration of atropine (0.01 to 0.02 mg/kg) or glycopyrrolate (0.005 to 0.01 mg/kg) to prevent bradycardia and hypotension is now less common with the change from halothane to sevoflurane for standard pediatric inhalational induction.

When performing direct laryngoscopy, the head is held in extension with the right hand while the laryngoscope is inserted at the right side of the mouth. Scissoring open the mouth with one's index finger and thumb, a technique commonly used in adult laryngoscopy, is not performed in infants and small children, as the small mouth opening

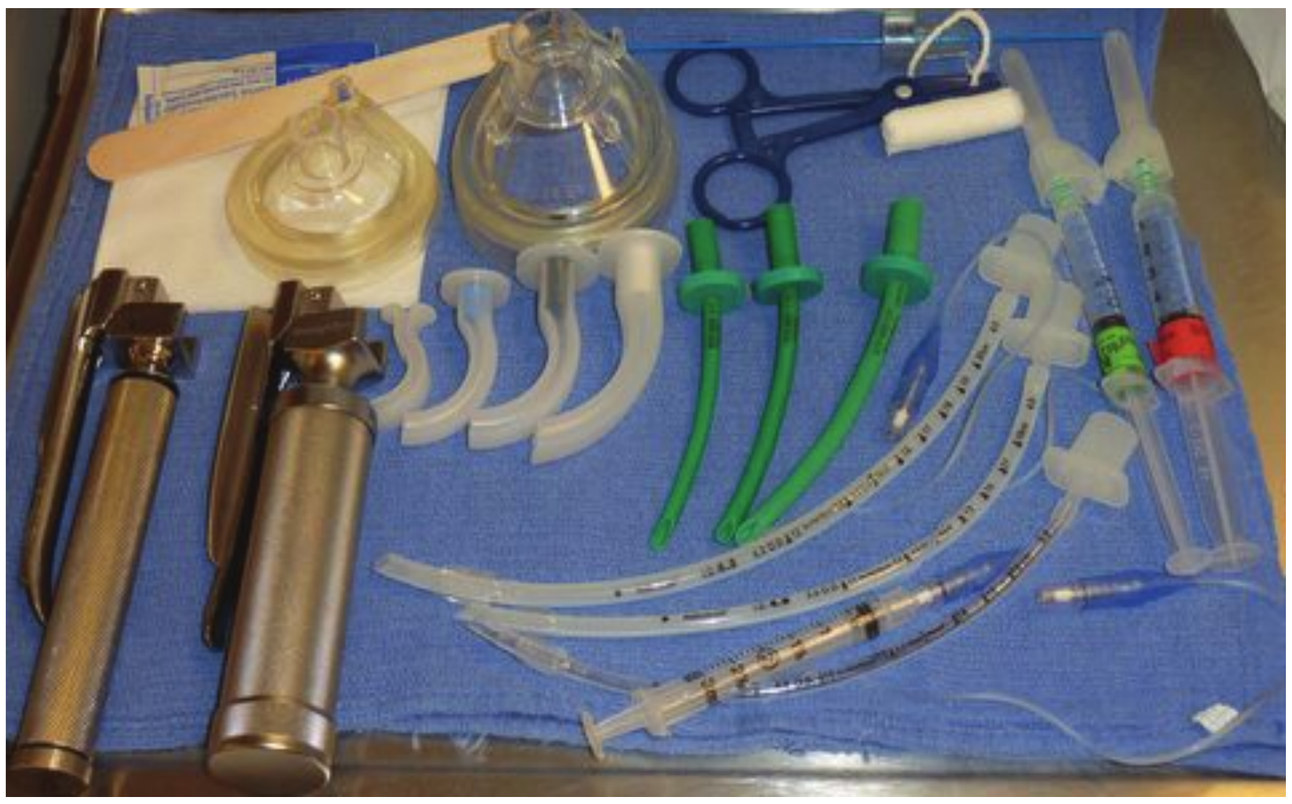


FIGURE 41-1 Routine equipment for pediatric airway management.



FIGURE 41-2 Routine positioning for seated direct laryngoscopy in a neonate.



FIGURE 41-3 Should this patient receive succinylcholine? The FDA has issued a black box warning for routine use of succinylcholine in pediatric intubations due to concerns regarding hyperkalemic cardiac arrest in patients with undiagnosed Duchenne muscular dystrophy.

Table 41-1

Choice of pediatric laryngoscope blade

Age	Blade Choice
Preterm	Miller 00
Neonate	Miller 0
Neonate–2 y	Miller, Phillips 1
2–6 y	Phillips 1, Wis-Hipple 1.5, Macintosh 1
6–10 y	Miller 2, Phillips 2, Macintosh 2
>10 y	Miller 2-3, Phillips 2, Macintosh 2-3

prevents proper insertion of the laryngoscopic blade. As with adult laryngoscopy, the blade should barely touch the upper teeth and lip, and the upper teeth should certainly never be used as a lever to pivot the laryngoscopic blade. After insertion into the mouth, the blade is then moved toward the midline, displacing the tongue toward the left side of the mouth, advancing toward the epiglottis to expose the larynx. The blade should not be advanced into the esophagus, achieving laryngeal visualization upon removal of the blade, as this technique may cause laryngeal trauma by scraping the arytenoid and aryepiglottic folds. In older children, a curved blade may be used with an approach similar to adult laryngoscopy, placing the blade into the vallecula and indirectly lifting the epiglottis to expose the larynx. However, in infants and young children, the unique anatomical considerations described in the previous chapter make the straight blade laryngoscope a superior blade as it is more capable of elevating the base of the large pediatric tongue, facilitating laryngeal visualization. The straight blade may be used in various ways. It may be used to directly lift the epiglottis, taking care to avoid traumatizing the delicate mucosa of the airway. However, it may also be placed in the vallecula, similar to a curved blade, thereby lifting the tongue and indirectly the epiglottis, facilitating laryngeal exposure. The Phillips blade, a straight blade with a curved tip, may be especially beneficial using this method. External laryngeal pressure may also improve the laryngoscopic view. The choice of blade size depends on the age and BMI of the child as well as the anesthesiologist's preference (Table 41-1). Although practices vary among practitioners, in the opinion of this author, a stylet should be used to facilitate placement of the ETT. The first attempt at intubation should use to advantage the best available equipment.

Selection of an appropriately sized ETT depends on several factors. Traditional teaching has advocated that only uncuffed tubes should be used in children below the age of 8 to 10 years. Advantages cited by proponents of the uncuffed ETT include avoidance of mucosal trauma to the subglottis due to the presence of a leak, cricoid sealing (long-held belief that the cricoid cartilage is the narrowest part of the pediatric airway), and the ability to place an ETT of larger internal diameter. The larger ETT would then allow for lower resistance to airflow (Poisseuille's law) and decreased work of breathing under spontaneous ventilation. The only studies supportive of the uncuffed approach are older descriptive studies rather than comparative studies. In truth, there are multiple troublesome issues with the placement of uncuffed ETTs. Air leaks can vary substantially with positioning and sedation, and profound changes in gas exchange may exist during mechanical ventilation. Ventilation may be extremely difficult in patients with acute lung injury, with poor lung compliance mandating increased airway pressures. Furthermore, measurements of lung mechanics and tidal volume are overestimated.

The introduction of newer high-volume, low-pressure (HVLP) cuffs (the HVLP revolution) allows for lower inflation pressures in producing a seal, with less risk of tracheal trauma with prolonged intubation (Fig. 41-4). The cuffed ETT is more economical due to the use of lower fresh gas flow. Cuff volumes are adjustable in sealing air leaks, avoiding multiple direct laryngoscopies in determining correct tube size. Cuff pressure must be monitored very closely with frequent gas removal, to maintain

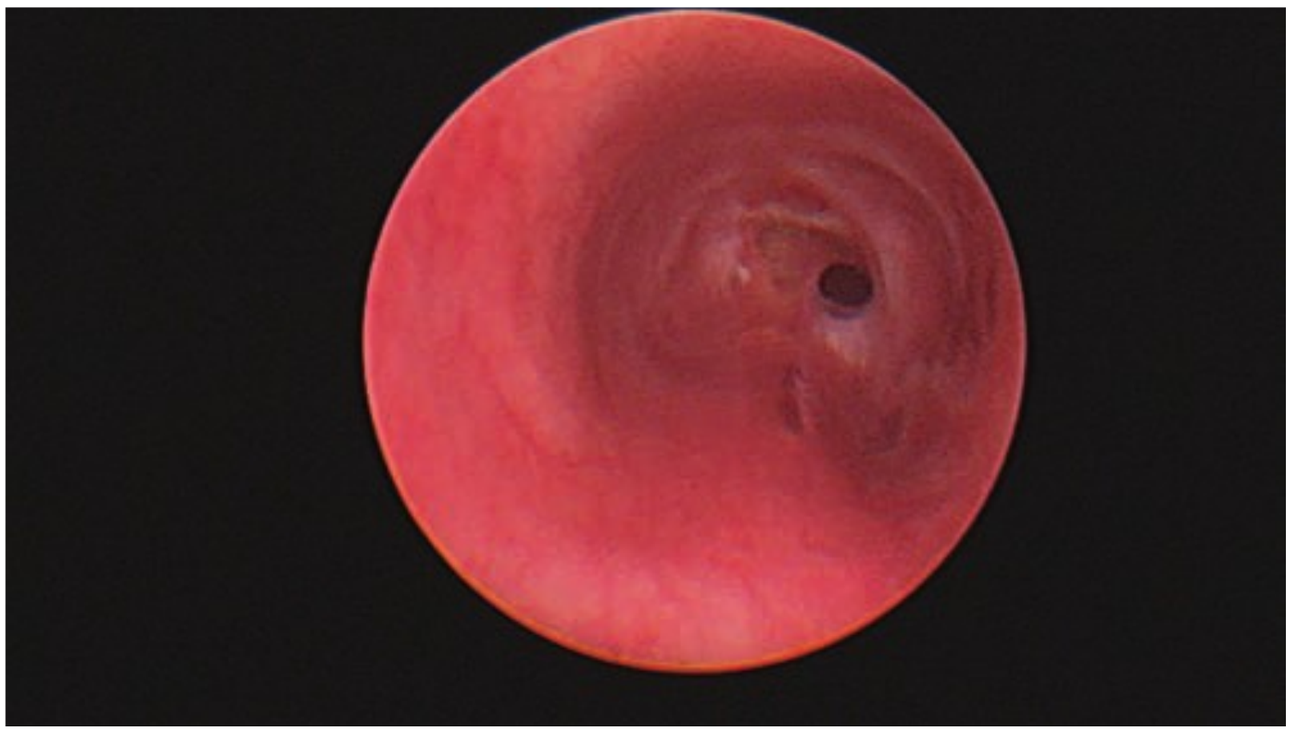


FIGURE 41-4 Subglottic stenosis after prolonged neonatal intubation.

pressures <25 cm H_2O, approximating capillary pressure of the tracheal mucosa. This in turn, avoids ischemia to the subglottic mucosa and minimizes the incidence of postoperative croup. Other advantages include the reduced risk of aspiration or airway contamination, improved $EtCO_2$ monitoring, and reduced operating room pollution with anesthetic gases. Studies supportive of the use of cuffed ETT in pediatric patients include both descriptive studies and comparative studies elucidating the previously mentioned advantages of cuffed ETTs.

Unfortunately, however, older designs of the pediatric cuffed ETT including a Murphy eye at the distal shaft have led to a multiplicity of concerns. The only mandated size requirement for manufacturers is the internal diameter of the ETT. Identical ETT inner diameters (IDs) may have outer diameters that vary by as much as 0.9 mm. This is partly responsible for the multitude of formulas to predict proper tube size. In fact, most of these formulas were designed for uncuffed ETT. Above the age of 2 years, the most commonly used formula for determining the correct sized ETT is (age in years + 16)/4. Details for ETT placement in patients below the age of 2 years are listed in Table 41-2. All of these values are for uncuffed ETT and should be downsized one half-size for cuffed ETT placement. One should always have available ETTs of one half-size above and below the chosen size.

It should be emphasized that the use of the terminal phalanx of the second or fifth finger is not a reliable method of estimating appropriate ETT size. When placing the ETT, one must remember that the length of the trachea in children below the age of 1 year may vary from 5 to 9 cm and one must be particularly mindful of the possibility of endobronchial intubation in the setting of small but persistent changes in oxygen saturation (Fig. 41-5). Detection of $EtCO_2$ does not confirm the lack of an endobronchial intubation. Auscultation of bilateral breath sounds in the axillae and lung apices (not the anterior chest wall), observation of symmetrical chest expansion, and, especially, palpation of the cuff balloon in the suprasternal notch may be beneficial in confirming the precise location of the ETT. It is essential to place the cuff of the ETT sufficiently beyond the glottic opening to ensure a cuff-free subglottic zone as well as a cuff position guaranteed to be below the cricoid and far enough above the carina. Details for approximate insertion distances in neonates and infants are listed in Table 41-3.

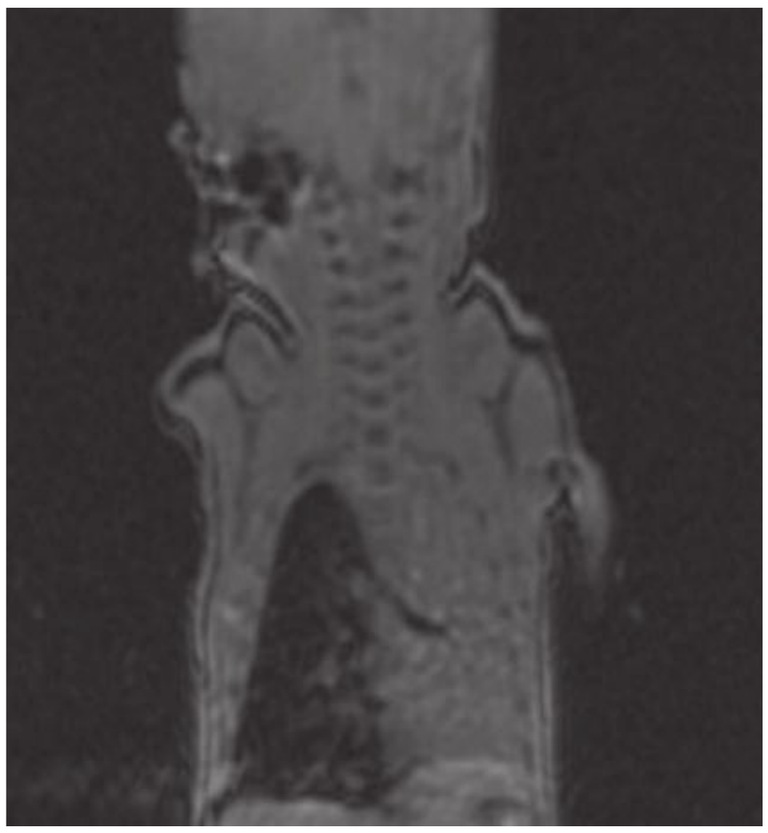


FIGURE 41-5 MRI of infant with persistent oxygen desaturation despite bilateral breath sounds revealing endobronchial intubation.

Recent investigations have revealed that the cricoid lumen is not a round structure but rather a mostly ellipsoid structure. This has important ramifications for the placement of cuffed and uncuffed ETTs. Cricoid sealing of an uncuffed ETT placed into the noncircular lumen of the cricoid still exerts considerable pressure on the posterolateral wall of the cricoid, despite the air leak arising from the anterior part of cricoid lumen. However, a cuffed ETT with a smaller diameter placed within the distensible trachea allows estimation and precise adjustment of the pressure exerted by the cuff on the tracheal mucosa. These investigations regarding the pediatric airway, combined with recognition of the inadequacies of current pediatric ETTs, have led to the development of the new Microcuff, comprising a very short HVLP cuff at the distal shaft with improved sealing characteristics (Fig. 41-6).

Table 41-2

Size of pediatric endotracheal tube

Age	ETT Size (mm ID)
Preterm	2.5–3.0
Neonate–6 mo	3.0–3.5
6 mo–1 y	3.5–4.0
1–2 y	4.0–5.0
Older than 2 y	(Age in years + 16)/4

Table 41-3

Position of pediatric endotracheal tube

Age	Insertion Distance (cm)
Preterm < 1 kg	6
Preterm < 2 kg	7–9
Term newborn	10
1 y	11
2 y	12

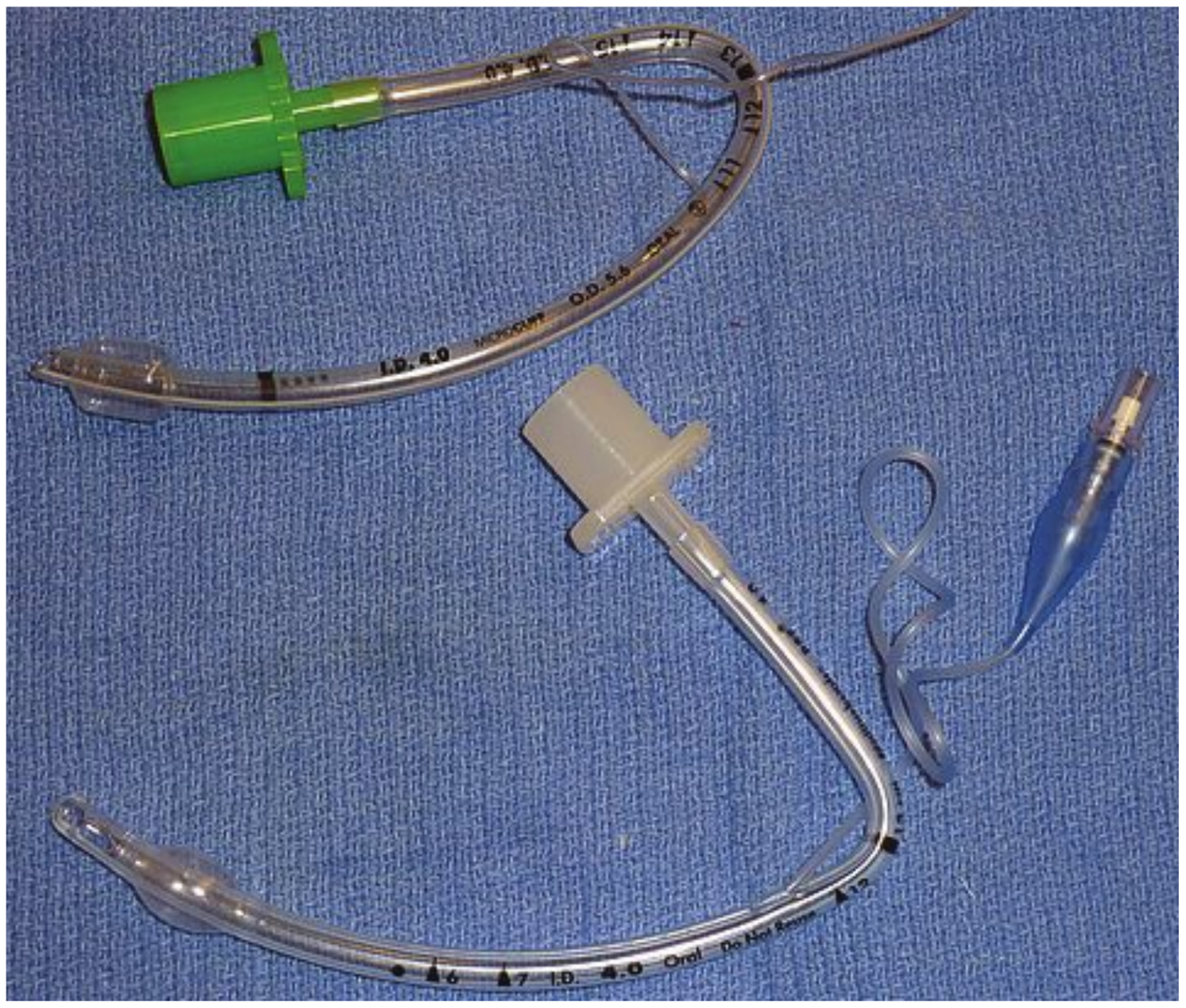


FIGURE 41-6 Comparison of the new Microcuff pediatric ETT to routine pediatric ETT revealing the cuff at the distal shaft of the ETT.

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CHAPTER 42

Adjuncts to Direct Laryngoscopy in Pediatrics

Jay B. Tuchman and Lawrence M. Borland

Any approach to management of the difficult pediatric airway must include both adequate preparation and a realistic recognition that the original plan may not be successful. In this context, prior to anesthetic induction, it is important to have conceived of alternate plans for securing the airway. Persistence in repeating the same technique, without making adjustments, or changing the approach, can induce trauma and edema within the delicate pediatric airway and rapidly transform a situation of "cannot intubate" into a more precarious scenario of "cannot intubate, cannot ventilate."

When practicing direct laryngoscopy with a standard laryngoscope, there are several maneuvers that may improve the laryngoscopic view, thus facilitating successful placement of the endotracheal tube (ETT). External pressure may be applied to the larynx, either by the laryngoscopist or an assistant, and may be particularly helpful during infant laryngoscopy. Placing a flexible stylet inside the ETT and using a hockey-stick shape may allow ETT placement, even when only the epiglottis or arytenoid cartilages are seen. The retromolar approach to direct laryngoscopy (Fig. 42-1) may be particularly useful in situations where routine rigid laryngoscopy is unsuccessful, such as in patients with micrognathia or macroglossia (Fig. 42-2). The head is turned slightly to the left, the right corner of the mouth is retracted, and a straight blade (Miller 1 with left-handed bulb or Phillips 1) is introduced through the right side of the mouth. The laryngoscope is advanced between the tongue and lateral pharyngeal wall, sweeping the tongue to the left, overlying the molars, until the epiglottis is visualized. The lateral placement of the blade and movement of the head bypasses the tongue, virtually eliminates the need for displacement of soft tissue, and improves line of site visualization.

The gold standard for management of the difficult airway remains the flexible fiberoptic bronchoscope. Proficiency in using this instrument remains a requisite skill for every practitioner. Positioning for fiberoptic bronchoscopy requires slight extension of the patient's head at the atlanto-occipital joint, with performance of a jaw thrust by an assistant, and at times, tongue traction, to open the posterior pharyngeal space and provide an ideal view of the glottic opening. The flexible bronchoscope should be kept straightened, with the tip of the scope placed in the midline. Specially designed oral airways facilitate midline placement during oral fiberoptic intubation, whereas nasal fiberoptic bronchoscopy typically allows for easier midline placement. However, the risk of epistaxis or adenoid shearing is ever-present, and, hence, premedication with topical vasoconstrictors is ordinarily undertaken. The modified nasal trumpet can be of great assistance when performing nasal fiberoptic intubation, permitting spontaneous ventilation. Both volatile anesthetics and oxygen may be provided via this route (Fig. 42-3). Due to the shorter airway distances in children, it is critically important to advance slowly through the identifiable supraglottic structures of the airway, thus avoiding deep placement of the fiberoptic scope in the esophagus. A pitfall of fiberoptic-assisted intubation is resistance to advancement of the ETT into the larynx, despite successful placement of the fiberoptic scope. To avoid catching the ETT on the arytenoid cartilages, one should place the ETT bevel **d**own on the fiberoptic scope for **o**ral intubations and bevel **u**p for **n**asal intubations (**UNDO**). One may also slightly withdraw the orotracheal or nasotracheal tube when resistance is encountered, rotate 90°, and attempt again.

Advantages of the flexible fiberoptic technique include its adaptability to multiple difficult airway scenarios, enabling the practitioner to secure the airway with minimal manipulation of the head or neck via both oral and nasal methods. This technique is particularly beneficial for patients with cervical instability; syndromic children with cervical inflexibility; and patients with temporomandibular joint (TMJ) abnormalities limiting translocation and, ultimately, rotation. Improved digital technology now allows for obtaining clearer images, even in the neonatal population, with the smallest scope sized 2.2 mm, and able to fit through a 2.5 ETT. Furthermore, light sources and video systems have been incorporated into the newer bronchoscopes, allowing for increased portability as well as the ability to display a larger image of the airway. However, there is a significant learning curve



FIGURE 42-1 Retromolar technique of pediatric laryngoscopy.



FIGURE 42-2 Macroglossia in a patient with Beckwith–Wiedemann syndrome requiring tongue reduction.

(Courtesy of Joseph Losee MD. Department of Pediatric Plastic Surgery at Children's Hospital of Pittsburgh.)

with the fiberoptic scope, and maintenance of one's skills requires continuous use. Other disadvantages include the narrow field of vision allowed by the fiberoptic bundle, the fragility and expense of the scopes, and the need for frequent cleaning and maintenance of the equipment. Excessive secretions or blood may render the scope unusable, particularly when using the neonatal scope, which lacks a channel for suctioning or administering local anesthetic.

A pediatric lighted stylet ("light wand"), equipped with a high-intensity light at the tip, may also be used to secure the difficult pediatric airway and is particularly helpful in patients with cervical spine fractures, due to the ability to achieve intubation without neck movement. Patients with micrognathia (Fig. 42-4) or TMJ disease, in whom there is a concern regarding laryngoscopic view, yet without any intrinsic laryngeal or oropharyngeal pathology, may be suitable choices for this approach. To achieve successful placement, one should curve the well-lubricated lighted stylet 45° to 90°, carefully maintaining the tip of the stylet within the tip of the ETT to avoid airway trauma. Dimming the room lights may be particularly helpful with this approach. The stylet is passed along the curvature of the tongue until a clearly circumscribed circular light transilluminates the middle of the neck. The ETT is then gently advanced off the stylet into the trachea. The most common difficulty in using this technique is that the ETT catches on the epiglottis. This may be corrected by withdrawing the stylet and placing it more posteriorly, allowing placement of the ETT underneath the epiglottis, or by rotating the bevel of the ETT. Drawbacks to this technique include the possible risk of bleeding, secondary to blind insertion of the stylet. Use of the lighted stylet is also restricted to larger children and insertion of larger



FIGURE 42-3 Modified nasal airway for pediatric nasal flexible fiberoptic bronchoscopy.



FIGURE 42-4 Micrognathia in a patient with Pierre Robin sequence.

(Courtesy of Joseph Losee MD. Department of Pediatric Plastic Surgery at Children's Hospital of Pittsburgh.)

ETTs, due to the large diameter of the stylet. The lighted stylet may also be less successful in obese patients and should not be used to secure the airway in the presence of airway tumors, laryngeal injuries, and retropharyngeal abscesses.

The Shikani optical stylet is a rigid, yet malleable metal stylet with a fiberoptic light source, which delivers an image to an eyepiece or video camera. This device may be used for oral intubation, does not require neck extension, and offers the advantage of displacing soft tissue and enabling oxygen delivery during intubation attempts. Most often, direct laryngoscopy is performed prior to insertion of the device. As with other fiberoptic techniques, this device requires a significant learning curve, may be quite fragile, and may be rendered ineffective by fogging, blood, and secretions. A benefit of the optical stylet over

flexible fiberoptic laryngoscopy is the ability to visualize the tip of the ETT as it passes into the trachea.

The first indirect laryngoscope using fiberoptic technology, the Bullard (Circon, Stamford, CT, USA), was originally designed for use in the difficult pediatric airway. The device is particularly beneficial in patients without neck extension and should be positioned like a laryngoscopy blade within the larynx, using a 90° bend to provide improved visualization around the base of the tongue in syndromic patients with mandibular hypoplasia. The styletted ETT, with a similar curve as the Bullard laryngoscope, is advanced into the trachea under direct visualization after achieving an adequate laryngeal view. The method of visualization with this device is vastly different than standard laryngoscopy and thus requires a significant learning curve to achieve consistent success.

A multitude of new video laryngoscopes has been designed for use in children, including those with camera integration into the laryngoscope blade, such as the GlideScope Cobalt (Verathon, Bothwell, WA, USA) and Storz video laryngoscope (Karl Storz, Tuttlingen, Germany), as well as those using prisms and mirrors, such as the Airtraq optical laryngoscope (Prodol Meditec, Vizcaya, Spain) and Truview EVO2 (Truphatek International, Netanya, Israel). All of these devices permit the head and neck to remain in a neutral position, may be used as teaching tools, and share the advantage of bearing a certain similarity to intubation with a standard laryngoscope. However, video laryngoscopy still requires coordination of the practitioner's focus on the video monitor with the manual dexterity of his or her hands. All of these devices require at least some mouth opening to pass the device, and may be complicated by fogging, blood, and secretions. Airway trauma may occur as a result of blind passage of a styletted ETT into the oropharynx, and most importantly, a good laryngeal view does not guarantee ease of ETT placement. Each of these new videolaryngoscopy devices has its own particular advantage. The GlideScope Cobalt has multiple sizes of blades for different ages of children, as well as a warming device at the tip of the blade to reduce fogging. The Storz video laryngoscope can be used for direct laryngoscopy and converted to video laryngoscopy, a particularly useful tool in the suspected, but unconfirmed, difficult pediatric airway. The Airtraq is also available in several sizes and has a lens warmer to prevent fogging, but requires warmup time for this mechanism to work. The particular advantage of this device is its portability and one-time disposable use, making it well suited for non operating room use. The Truview EVO2 provides a wide-angle magnified view and provides an infant blade with a port for oxygen insufflation.

Perhaps the most versatile approach for the difficult pediatric airway is the use of the laryngeal mask airway (LMA) as a conduit for insertion of the ETT. The LMA may serve as an adjunct for ventilation, while attempts to secure the airway via intubation are in process. Although blind intubation may be accomplished via the classic LMA, as the distal opening of the LMA is often at the glottis, the most successful method for LMA-guided intubation in children uses the flexible fiberoptic scope to advance the ETT through the LMA. An important limitation of this approach in the infant population is the inability to pass the pilot balloon of a cuffed ETT through the LMA. One choice is to place an uncuffed ETT and use another ETT as a "pusher" when removing the LMA. However, the great advantages of placing a cuffed ETT in this patient population have already been described in detail in the previous chapter. To avoid the need for placement of an uncuffed ETT, with subsequent cumbersome cuffed ETT exchange and associated risk of extubation, one can cut the pilot balloon to facilitate placement of the cuffed ETT and then reconstruct the pilot balloon (Fig. 42-5). This may be done by inserting an IV catheter into the cut end of the tubing, removing the needle, and attaching a one-way Luer lock valve port adapter to the end of the IV catheter. Another approach, using the specialized Air-Q LMA, facilitates placement of a cuffed ETT by employing a flexible fiberoptic scope, without the

FIGURE 42-5 Reconstruction of the pilot balloon after LMA-guided fiberoptic intubation with a cuffed ETT.

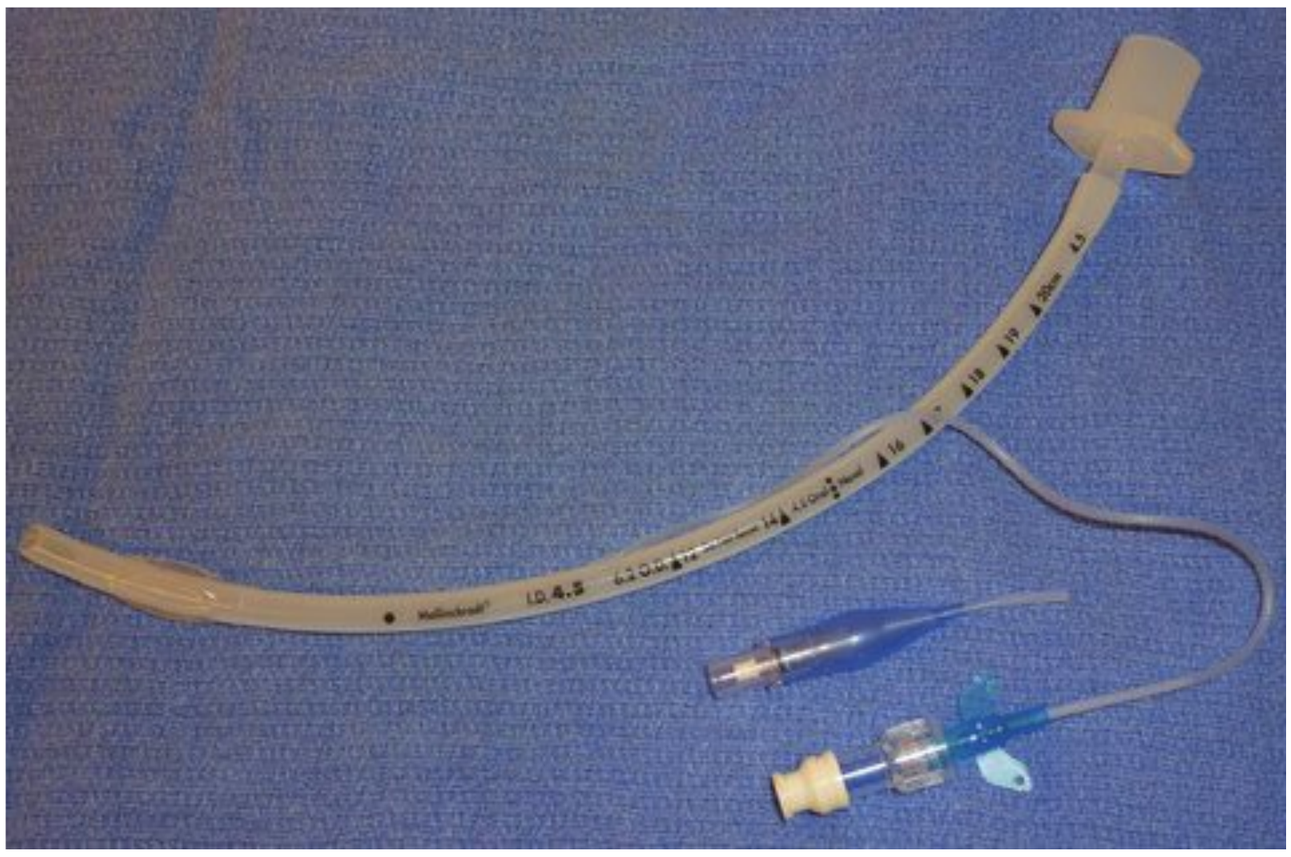




FIGURE 42-6 Comparison of the wider and shorter shaft of the new Air-Q LMA with the classic LMA facilitating LMA-guided flexible fiberoptic intubation.

need for dismantling the pilot balloon. The airway tube of the Air-Q is wider and shorter than the standard LMA, accommodating the pilot balloon and minimizing the risk of accidentally pulling the ETT when removing the LMA (Fig. 42-6). There is a stabilizer bar provided by the manufacturer, which wedges inside the ETT, allowing successful removal of the LMA without catastrophic removal of the ETT, after securing the difficult airway.

In conclusion, recent technological advances have widened the array of tools, and consequently approaches, available in the pediatric anesthesiologist's armamentarium. Each practitioner should become comfortable with a few of these techniques in the normal pediatric airway, thereby facilitating management when faced with the truly difficult pediatric airway.

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PART XII Bronchoscopy

CHAPTER 43

Rigid Bronchoscopy

Peter Ferson

INTRODUCTION

The application of endoscopic methods to evaluate and treat disorders of the airways is an essential skill for the clinician who practices anesthesiology, thoracic surgery, pulmonary medicine, or otolaryngology. As with most facets of practice, endoscopic technology is constantly changing. The clinician must, therefore, be aware not only of the historical development of techniques, but also of currently available methods and instrumentation, so that he may properly select the appropriate equipment and use it effectively.

HISTORY

Although ancient physicians from Greece and the Middle East clearly made efforts to peer into body orifices using specula, Bozzini seems to have been the first to create a device specifically designed to direct light into a cavity. He described his lichleiter in 1806. This used a wax candle as a light source and a mirror directing the light into the various parts of the body so that he could examine through a lens. He is reported to have performed vaginal, rectal, and pharyngeal examinations with this instrument.[1–3] The first clear use of an endoscopic technique to examine the airway was by Gustav Killian in 1897. For his initial efforts, he hired a paid volunteer but later successfully removed a foreign body from the airway.[4] The use of various tubes, light sources, and lens systems flourished in the early half of the 20th century. A major contributor in the United States to the development of the techniques and devices was Chevalier Jackson who practiced bronchoesophagology in Pittsburgh and Philadelphia. He is widely considered to be the father of American otolaryngology.[5] In 1968, Ikeda[6] first reported on the use of the flexible fiberoptic bronchoscope. The ease of use and patient comfort with this device allowed it to quickly overshadow the rigid bronchoscope for the purpose of examination of the airways.

BRONCHOSCOPE

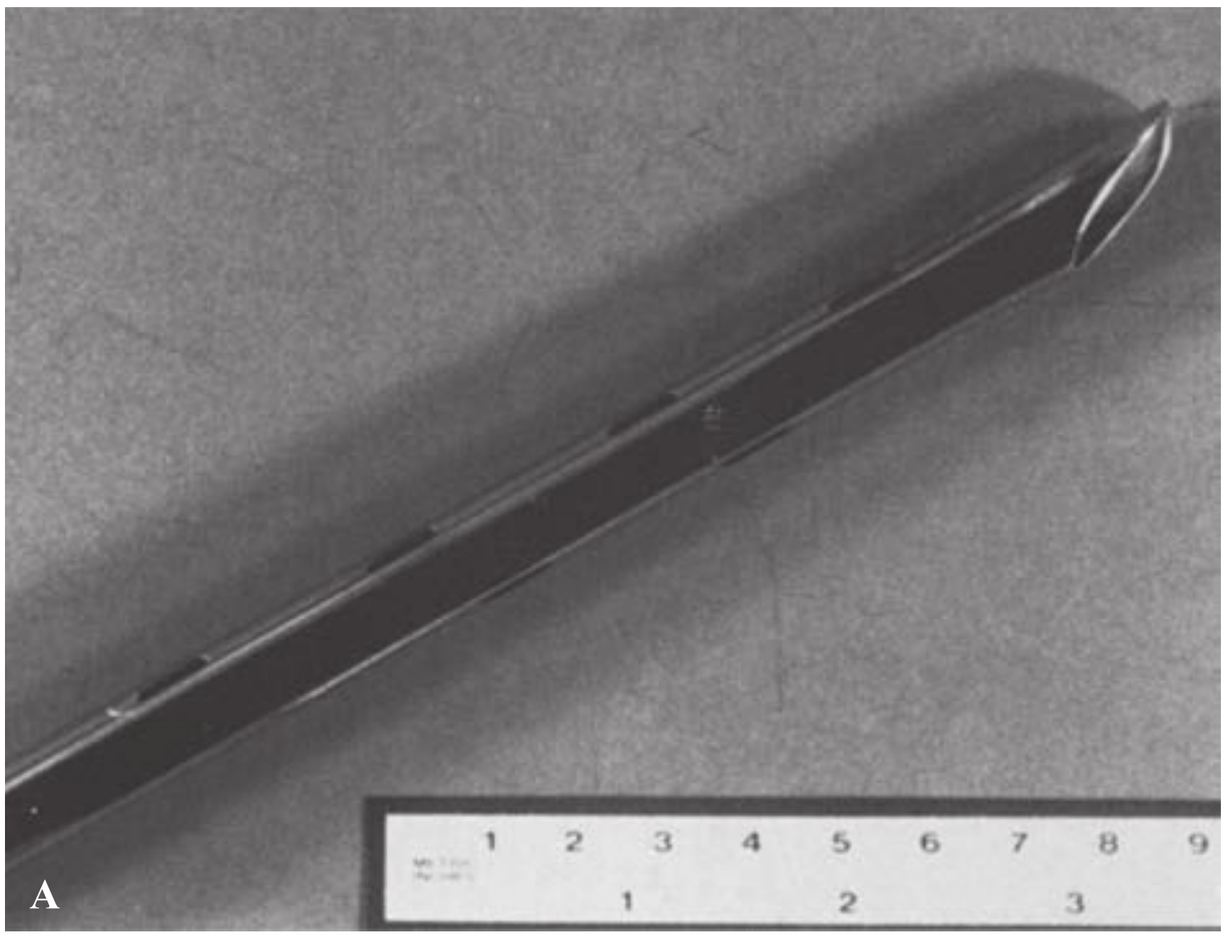
The rigid bronchoscope is a hollow tube, with a fiberoptic light source usually conveyed to the distal end. The distal end is beveled to facilitate insertion and maneuvering in the airway. There are side openings in the distal end to permit ventilation of the contralateral bronchus, when the scope is introduced into a distal bronchus. The tubes come in various diameters and lengths. Proximally there is an opening for viewing and working. Viewing is enhanced by inserting a telescope and camera through the tube. The proximal opening may be occluded with a window plug if a closed system is desired, or to prevent backflow of contaminated material. There is a side port for attaching a ventilation circuit and a smaller port for connecting a jet ventilator (Fig. 43-1).

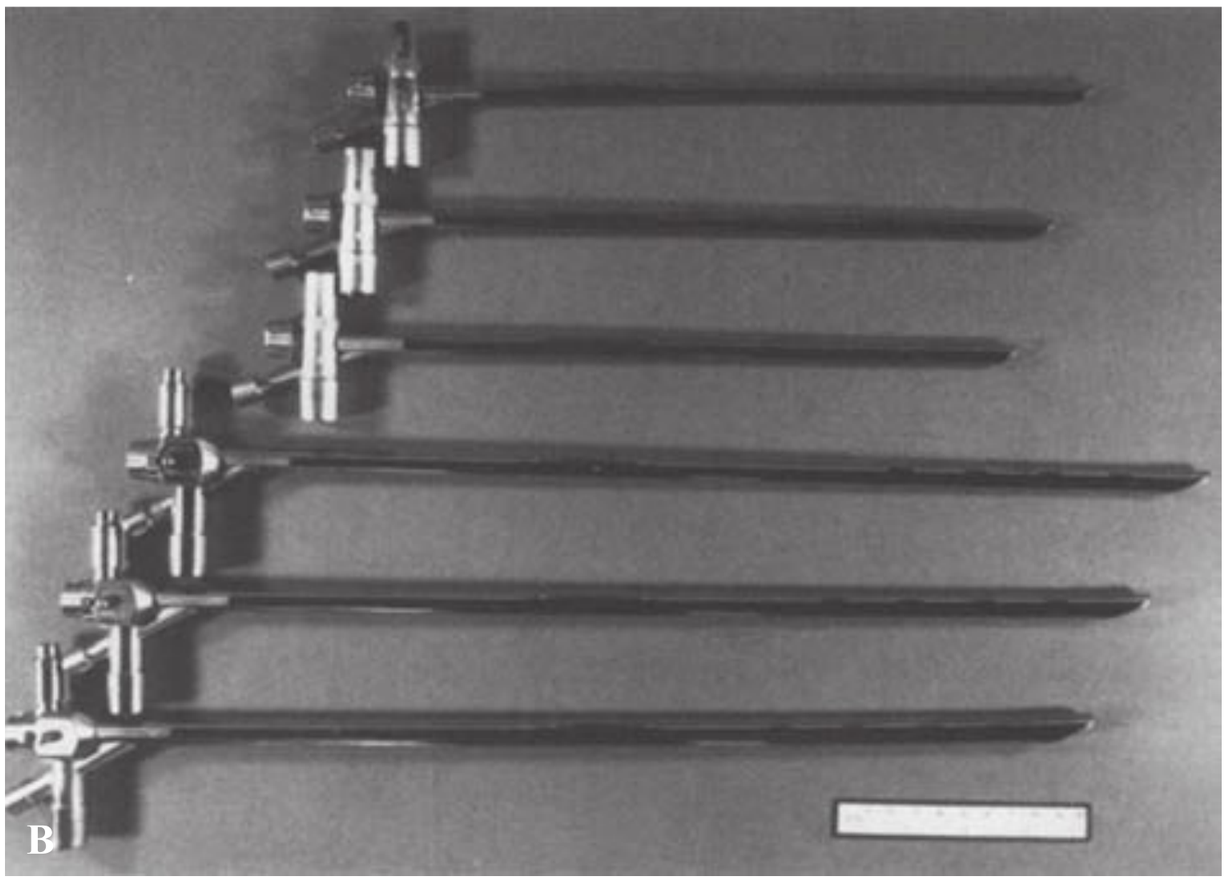
PATIENT SELECTION

There are several indications for considering rigid bronchoscopy. This method is clearly more effective than flexible bronchoscopy in clearing thick inspissated secretions or blood. When confronted with significant bronchial bleeding, clearing the blood, packing off the offending bronchus (with hemostatic gauze), and ventilating the contralateral lung requires rigid bronchoscopy. Many foreign bodies can be removed by flexible bronchoscopy, but the more troublesome ones that are elusive, large, or impacted can be best dealt with by rigid bronchoscopy. Obstructing tumors in the trachea and mainstem can be debrided more expeditiously with a rigid bronchoscope, and flexible laser bronchoscopy can be performed through a rigid bronchoscope to combine the advantages of each technique. The indications for rigid bronchoscopy are listed in Table 43-1.

INSERTION TECHNIQUE

Insertion of a rigid bronchoscope should be accompanied by an initial examination of the facial anatomy and the upper airway, as one would perform for standard





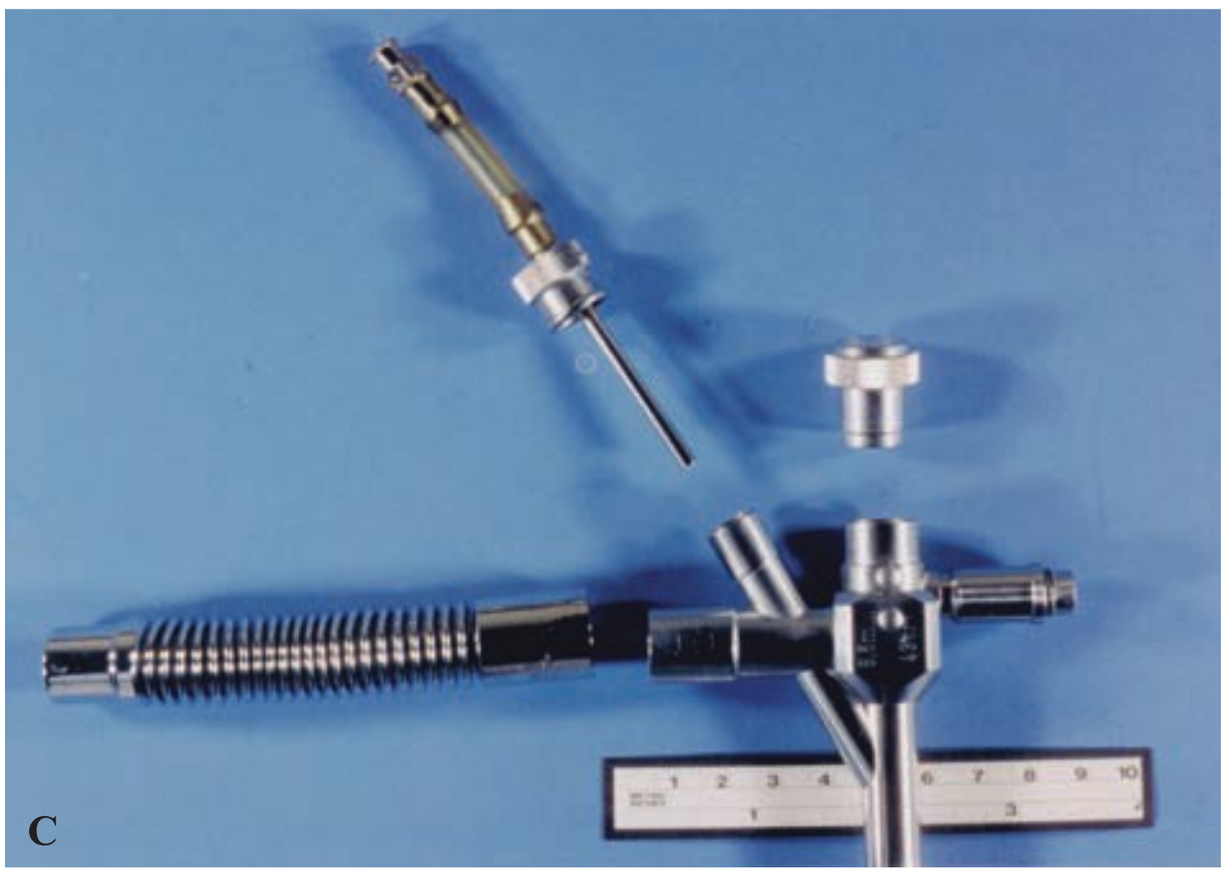


FIGURE 43-1 **A:** Tip of a bronchoscope. The ventilation side ports permit aeration of the contralateral bronchus when the tip of the scope is impacted in the bronchus being examined. The beveled end of the bronchoscope facilitates passage through the larynx, past the carina, and into the distal mainstem bronchi. **B:** Bronchoscopes are available in various diameters and lengths. Inner diameters range from 3 (not shown) to 8.5 mm. Maintenance of a complete set of sizes is vitally important in a facility in which procedures are performed on both children and adults. C: The working end of the rigid bronchoscope has connections for a ventilator adaptor, a jet ventilation port, a window plug to occlude the working channel if desired, and a light connector for the fiberoptic light cord (not shown).

(Reused with permission from Ferson PF, Eibling DE. Bronchoscopy and tracheoscopy. In: Myers EN, ed. Operative Otolaryngology: Head and Neck Surgery. 2nd ed. Philadelphia, PA: Elsevier/WB Saunders; 2008.)

Table 43-1

Indications for Rigid Bronchoscopy

Examination of the upper airway
Obtaining large biopsies
Removal of thick secretions
Control of significant bleeding
Extraction of foreign bodies
Evaluation and dilation of strictures
Endobronchial debridement of tumor
Stent placement

endotracheal intubation. The ideal patient for rigid bronchoscopy is thin and edentulous, with a long supple neck and a generous mouth opening. Such a patient is rare. Features such as prominent teeth, small mouth with a receding chin, and cervical fixation or kyphotic posture, all contribute to making the procedure more difficult and thus more hazardous. Although none of these features will be an absolute contraindication to performing rigid bronchoscopy, the endoscopist must carefully weigh the risks presented by patient anatomy before proceeding.

Although topical anesthesia and sedation have been used for rigid bronchoscopy, in most instances general anesthesia is appropriate. Induction should proceed as for standard intubation. The patient may be first intubated with an endotracheal tube to have the airway controlled, and then once stabilized, the table should be turned 90° with the anesthesiologist now at the patient's left and the endoscopist sitting at the head of the table above the patient. Monitoring with a pulse oximeter is appropriate; rarely is an arterial line necessary. If the patient is intubated, the endotracheal tube is withdrawn and the bronchoscope inserted in the described fashion. Ventilation is established by a jet ventilator directly through the bronchoscope or by intermittent positive pressure ventilation with a closed system including a window plug.

It is not necessary to have an endotracheal tube placed initially, particularly if the endoscopist is comfortable with the technique of introducing the bronchoscope. With this method the bed is turned 90° before induction, and the endoscopist holds the ventilating mask with an appropriate mouthpiece until the patient is fully anesthetized, and the larynx is then intubated with the bronchoscope as one would perform with the endotracheal tube. If there is no question about the integrity or the exposure of the airway then muscle relaxation is undertaken prior to inserting the rigid bronchoscope.

There are two methods that are appropriate for the introduction of the bronchoscope into the airway. In the first, the bronchoscope is used as a laryngoscope, being inserted between the palate and the tongue, depressing the tongue anteriorly until the uvula is identified, and then lifting the tongue and mandible to identify the tip of the epiglottis. The leading edge of the bronchoscope is passed under the epiglottis and then rotated 90° so that the sharp vertical axis of the bronchoscope is oriented anterior to posteriorly. While supporting the bronchoscope on the mandible or upper teeth, with the left fingers on the teeth and the thumb supporting the bronchoscope, the edge is advanced between the vocal cords so that the left vocal cord is visualized and the right vocal cord is displaced laterally. The head will often need to be lifted into an exaggerated sniffing position to accomplish this with the rigid bronchoscope. Once the tip is through the larynx the head can be lowered to allow the scope to match the axis of the trachea. When the tip has entered the larynx, ventilation may be established (Fig. 43-2).

The alternative method of introducing the rigid bronchoscope is preferred by the author. For this method, a laryngoscope is used. A Macintosh blade is ideal because a Miller blade would cause "sword fighting" along the same axis as the bronchoscope. Using a Macintosh blade, the airway is exposed holding the blade with the left hand and inserting the bronchoscope with the right hand again turning it 90° so that the vertical edge is in the same orientation as the opening between the vocal cords. As the bronchoscope is passed through the larynx, the laryngoscope is removed and the left hand is used to support the bronchoscope on the teeth or maxilla. Occasionally, with an anterior airway only the arytenoids can be seen through the rigid bronchoscope until the laryngoscope is removed and the left hand is used to direct the tip upwards and into the larynx. From this point, in both methods the procedure continues in a similar fashion, examining the airways, the trachea, and the mainstem bronchi as need be (Fig. 43-3).

VENTILATION

Ventilation during rigid bronchoscopy can be performed with standard positive pressure ventilation although usually with a significant air loss and with intermittent apnea. The preferred alternative is to use sustained jet ventilation. The jet ventilation may be accomplished with a manual jet trigger, but a dedicated jet ventilator facilitates smoother control of ventilation. The typical initial settings for a mechanical jet ventilator would be a frequency of 100 to 125 pulses per min with a driving pressure of 25 mm Hg (see Chapter 48). These settings may be adjusted for chest size and for adequate oxygenation. When using jet ventilation, it is essential to keep an open circuit. There is a natural tendency for those unfamiliar with this technique to place an occlusive window plug and to obstruct the outflow. This will result in increasing airway pressure and, ultimately, alveolar rupture. Also, with prolonged jet ventilation, there is a risk of elevated CO_2 levels, which

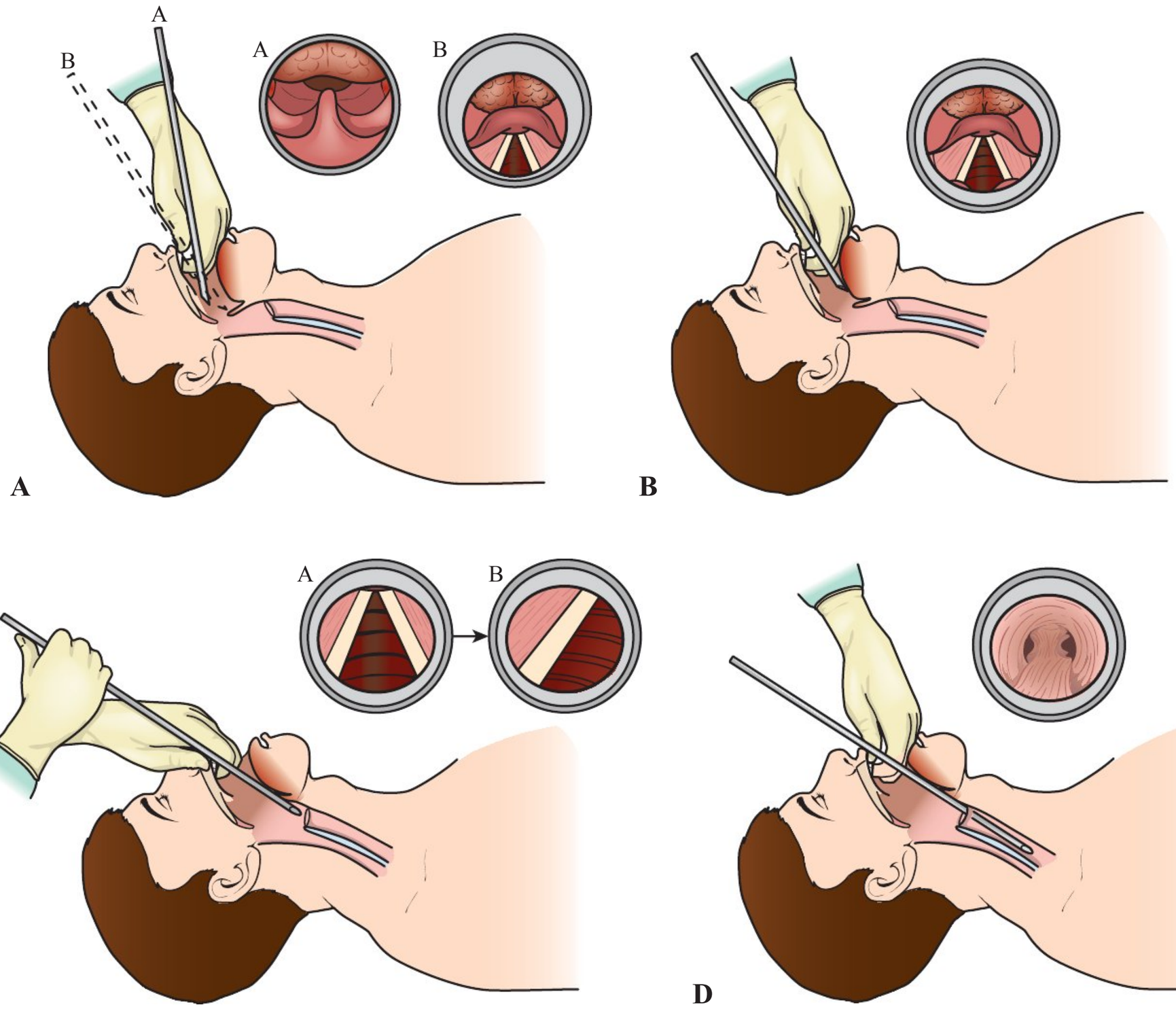


FIGURE 43-2 **A:** Technique of intubation. The bronchoscope is aligned in the midline of the tongue while the mouth is held open with the thumb and fingers. The bronchoscope is supported with the thumb, and the uvula **(A)** and epiglottis **(B)** are visualized to maintain midline orientation. **B:** The bronchoscope is advanced while aiming behind the epiglottis, and the larynx is visualized. **C:** With the tip of the bronchoscope behind the epiglottis, the initial view **(A)** will show both the right and the left vocal cords. This is not the correct position to advance the bronchoscope into the trachea. The bronchoscope is rotated 90° clockwise so that the leading tip of the beveled end is to the right lateral side. The entire bronchoscope is shifted laterally to expose the left vocal cord **(B)**. With this exposure and this orientation, the bronchoscope may be advanced safely into the trachea without causing trauma to the right vocal cord. The left vocal cord will slide along the bevel and be pushed laterally as the bronchoscope enters the trachea. **D:** The bronchoscope has been advanced past the larynx into the trachea for distal tracheal examination. It is important at this point that the upper hand be placed in a firm position to protect the teeth and upper jaw from pressure from the bronchoscope. The bronchoscope should rest on the left thumb and not against the teeth; this is a position similar to an open bridge, as used with a cue stick for shooting billiards.

(Adapted with permission from Ferson PF, Eibling DE. Bronchoscopy and tracheoscopy. In: Myers EN, ed. Operative Otolaryngology: Head and Neck Surgery. 2nd ed. Philadelphia, PA: Elsevier/WB Saunders; 2008.)

may require standard intubation, and hyper-ventilation to correct.

For prolonged procedures, when hypoxia develops during jet ventilation, attaching the anesthesia circuit with high flow oxygen may entrain oxygen through the side ventilation port of the bronchoscope, still leaving the system open. If this is inadequate, then the system can be closed, the jet discontinued, and positive pressure established by placing a glass window plug on the end of the bronchoscope, and holding the nose and mouth closed around the bronchoscope tube. Once full oxygenation has been reached, discontinuing the positive pressure and resuming jet ventilation will allow for continued working through the bronchoscope.

Complications in this procedure are relatively infrequent. Trauma may occur with insertion, involving dentition, the oral cavity, the pharynx or airway itself. Inadequate ventilation may result in hypercarbia or hypoxia. With a closed system, barotrauma may occur, resulting in pneumomediastinum or pneumothorax.

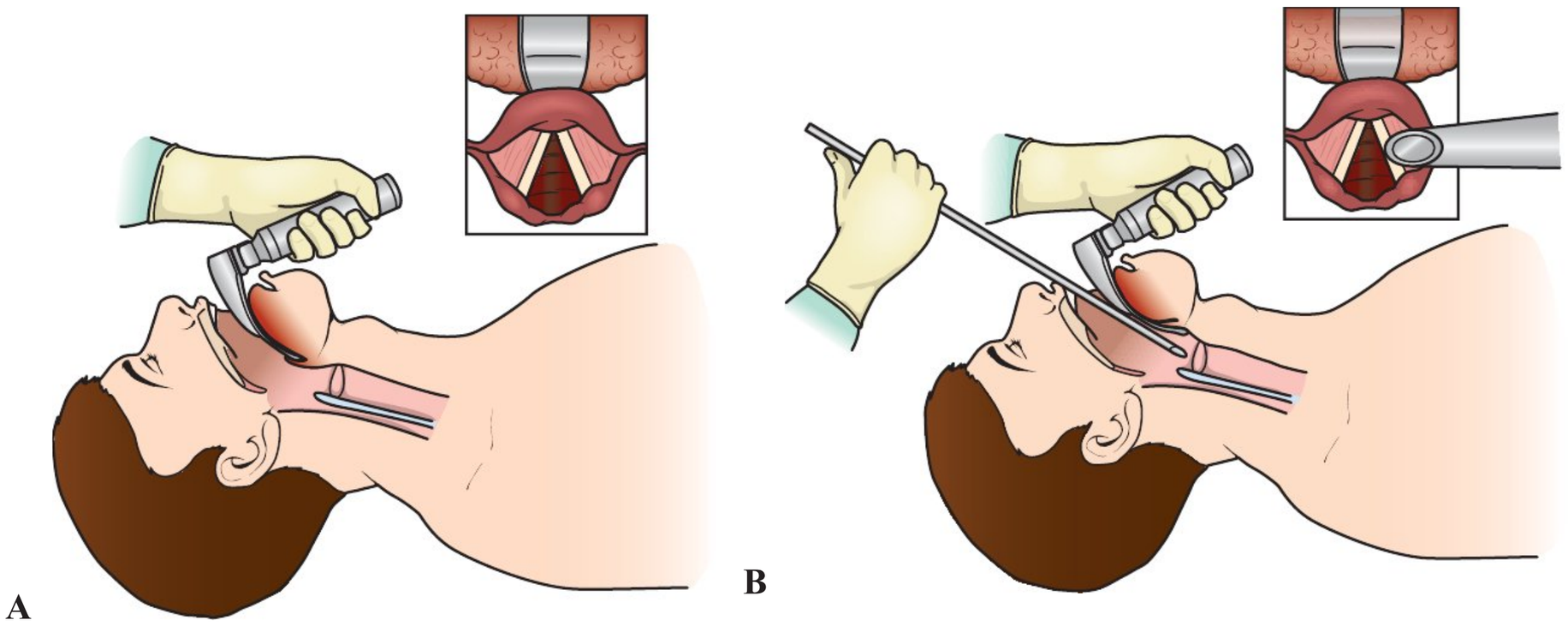


FIGURE 43-3 **A:** The larynx is exposed directly with an anesthesia laryngoscope that has a curved blade. The tongue base and epiglottis are elevated. **B:** While the larynx is visualized with the laryngoscope held in the left hand, the bronchoscope is inserted behind the epiglottis to the level of the vocal cords with the right hand. **C:** The operator's view is now directed down the shaft of the bronchoscope. The laryngoscope is removed, and the left hand is placed on the upper teeth to support the bronchoscope. **D:** With the tip of the bronchoscope behind the epiglottis, the initial view **(A)** will show both the right and the left vocal cords. This is not the correct position to advance the bronchoscope into the trachea. The bronchoscope is rotated 90° clockwise so that the leading tip of the beveled end is to the right lateral side. The entire bronchoscope is shifted laterally to expose the left vocal cord **(B)**. With this exposure and this orientation, the bronchoscope may be advanced safely into the trachea without causing trauma to the right vocal cord. The left vocal cord will slide along the bevel and be pushed laterally as the bronchoscope enters the trachea. **E:** The bronchoscope has been advanced past the larynx into the trachea for distal tracheal examination. It is important at this point that the upper hand be placed in firm position to protect the teeth and upper jaw from pressure from the bronchoscope. The bronchoscope should rest on the left thumb and not against the teeth; this is a position similar to an open bridge, as used with a cue stick for shooting billiards.

(Adapted with permission from Ferson PF, Eibling DE. Bronchoscopy and tracheoscopy. In: Myers EN, ed. Operative Otolaryngology: Head and Neck Surgery. 2nd ed. Philadelphia, PA: Elsevier/WB Saunders; 2008.)

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CHAPTER 44

Diagnostic and Therapeutic Fiberoptic Bronchoscopy

Paul Bigeleisen

BACKGROUND AND EQUIPMENT

Although anesthesiologists frequently use flexible bronchoscopy to assist with difficult intubations and the placement of double lumen endotracheal tubes, they rarely examine the airway distal to the right and left mainstem bronchi. Nonetheless, anesthesiologists and more commonly intensivists, may be called upon to perform some forms of diagnostic or therapeutic bronchoscopy. This chapter summarizes the equipment used in and indications for flexible bronchoscopy that anesthesiologists and intensivists are likely to encounter.

The rigid bronchoscope was invented by Killian in 1897. Machida and the Olympus Corporation produced the first commercially available flexible fiberscope in 1966.[1,2] This device used glass fibers to conduct light into the airway and reflected light back to the viewer. In 2001, a new type of flexible scope with a light source in the cable and a digital camera at the tip of the flexible cable was developed.[3] The digital image formed by this miniature digital camera was carried back from the airway by copper wire to a viewing screen. This provided a superior image and eliminated the need for glass fibers in the image channel. The resulting image had a higher resolution without the pixilation inherent to the previous generation of fiberoptic scopes.

A flexible bronchoscope consists of a handle with controls attached to a flexible conduit with three channels. One channel is a hollow lumen that can be used to suction sputum, insufflate oxygen, inject saline/local anesthetic, or biopsy tissue. Another channel conveys light from the light source to the tip of the bronchoscope. The third channel returns the image of the airway from the tip of the bronchoscope to the eyepiece or viewing screen. Additional equipment consists of a light source, and a viewing screen or eyepiece (see also Chapter 23).[1–3]

INDICATIONS

Fiberoptic bronchoscopy is indicated for diagnostic and therapeutic problems of the airway and lungs. The most common diagnostic indications that anesthesiologists and intensivists will encounter are stridor, hoarseness, vocal cord paralysis, and infection. In addition, the fiberscope is usually used to confirm endobronchial tube placement (or diagnose displacement) during surgical procedures requiring lung isolation or single lung ventilation. Less common uses are to diagnose inhalation injury, hemoptysis, lobar collapse, and the identification of foreign bodies and obstructing tumors. Common therapeutic indications are the removal of foreign bodies, pulmonary toilet, bronchoalveolar lavage, and transtracheal percutaneous tracheostomy (see Chapter 39).[3]

ANATOMY OF THE AIRWAY (FIGS. 44-1–44-7)

The airway begins at the lips and traverses the oral cavity and hypopharynx (Figs. 44-1–44-7). More distally, the endoscopist encounters the epiglottis, false cords, true cords, and then the trachea. The trachea has the shape of a tunnel. The proximal trachea consists of the membranous posterior portion, which is largely flat striated muscle. The anterior portion is composed of cartilaginous rings and the thyroid and cricoid cartilages. Approximately 8 cm distal to the cords, the trachea bifurcates into the right and left mainstem bronchi; this bifurcation is called the carina. The architecture of the trachea is continued at this level with a membranous posterior portion and a cartilaginous anterior portion.

As the endoscopist travels distally down the left mainstem, the left bronchus bifurcates into the superior and inferior lobar bronchi. This bifurcation has a similar appearance to the carina. For this reason, it is often referred to as “the mini carina.” The superior lobar bronchus then gives rise to the superior division bronchus and the lingular bronchus. These bronchi give rise to segments that comprise the superior lobe of the left lung. The inferior lobar bronchus gives rise to four segments that comprise the inferior lobe of the left lung.

As the endoscopist travels distally down the right mainstem bronchus, he encounters the right superior lobar bronchus, which gives rise to the superior lobe of the right lung. Continuing down the right mainstem

FIGURE 44-1 Carina as viewed through flexible bronchoscope.

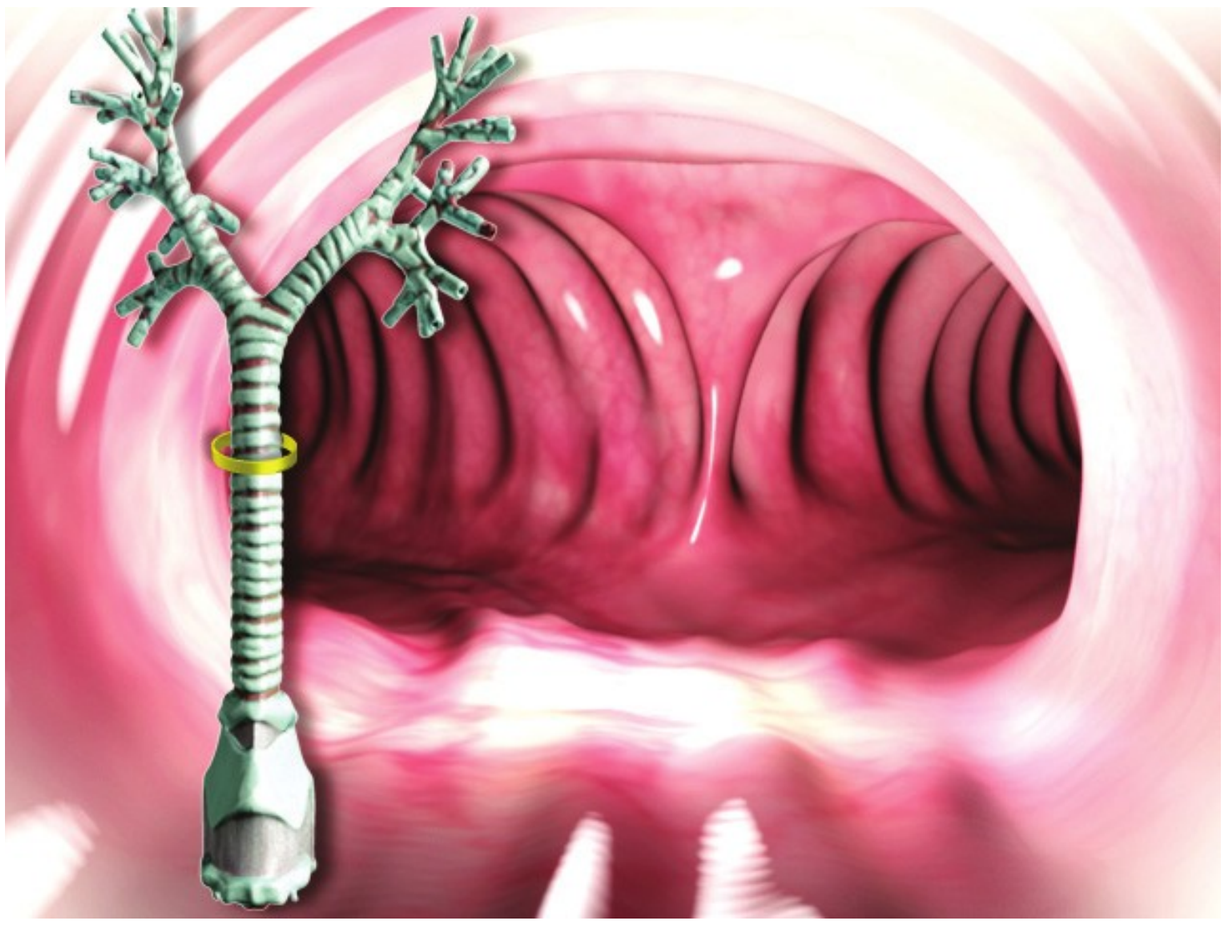
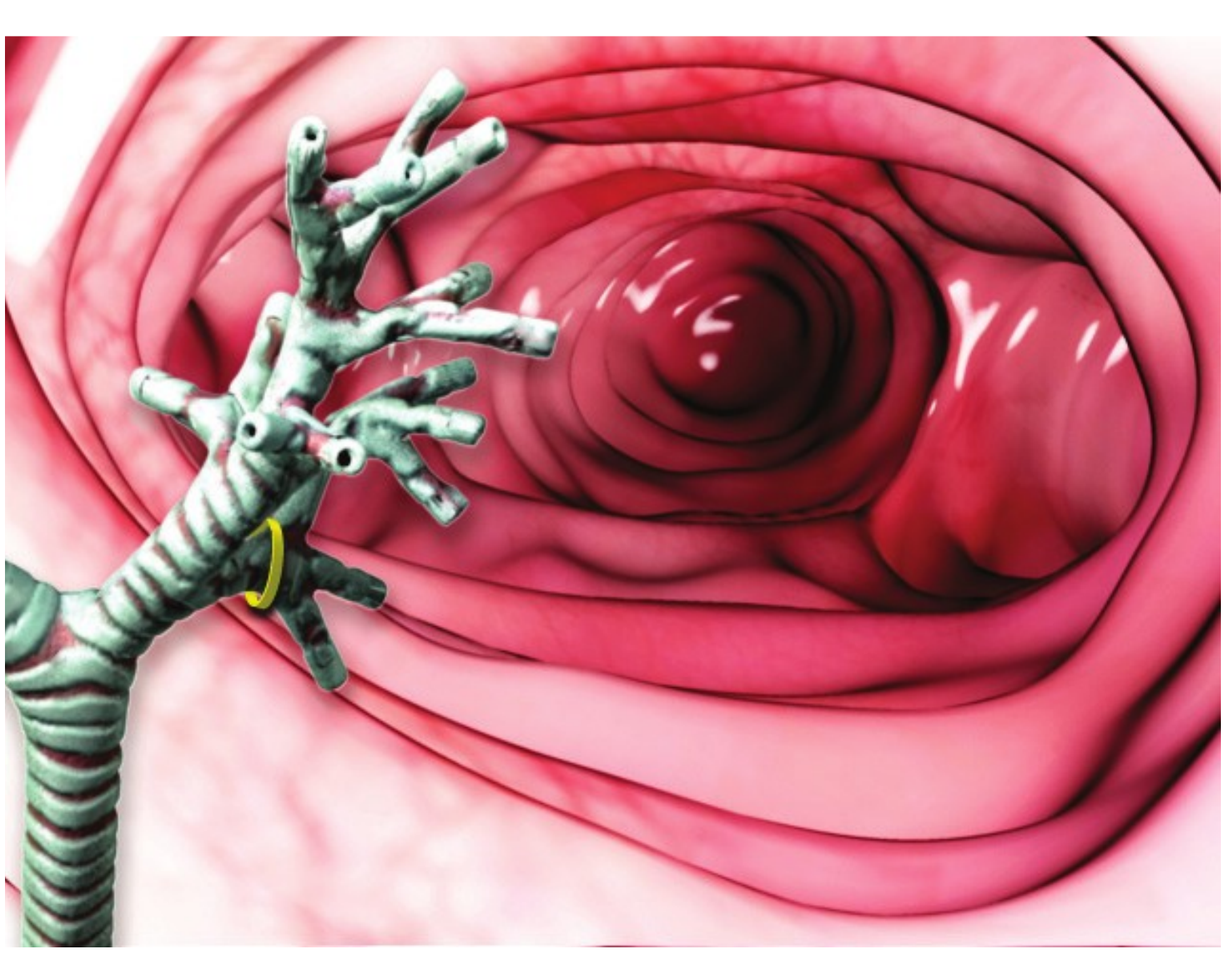


FIGURE 44-2 View of right mainstem bronchus.



FIGURE 44-3 View of right upper lobe bronchus.



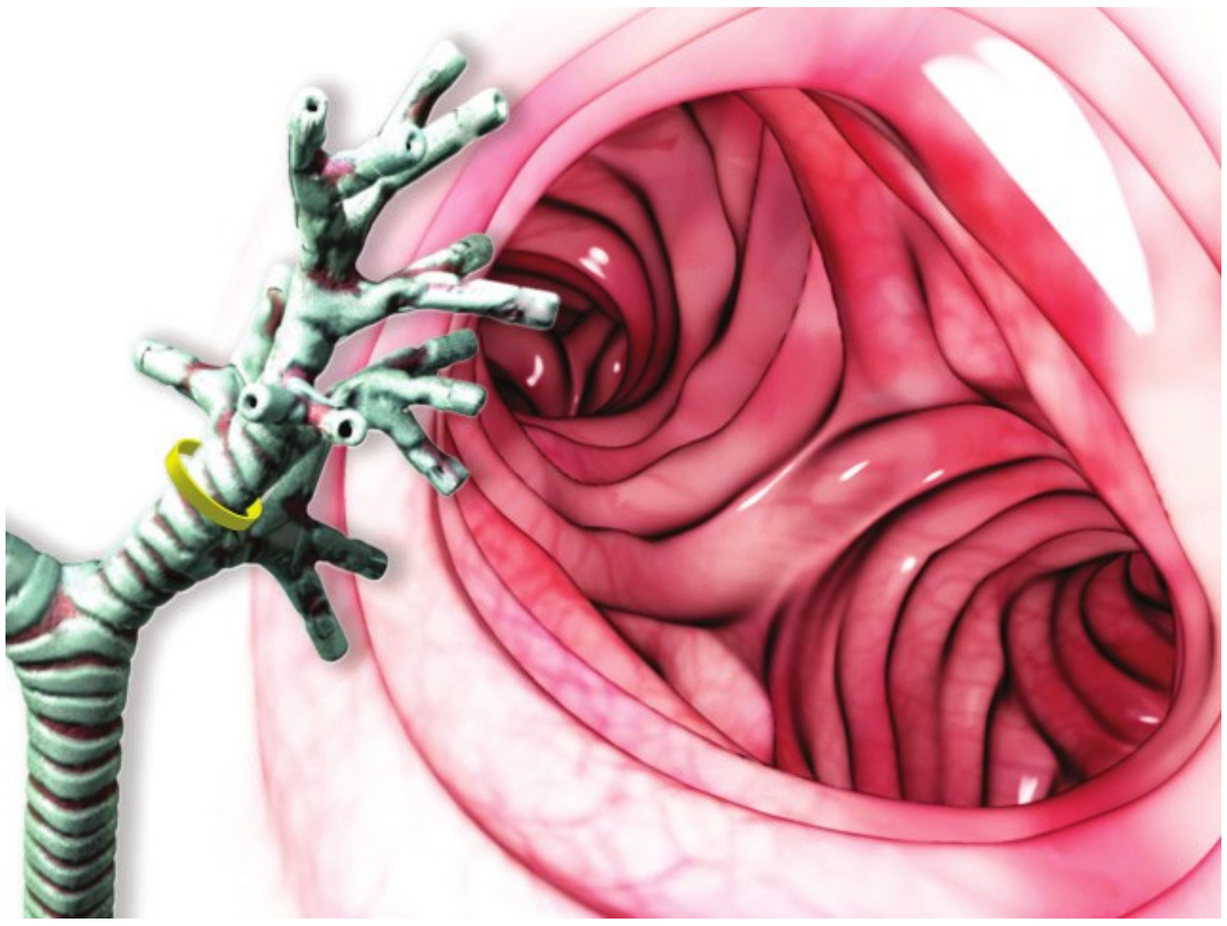


FIGURE 44-4 View of bronchus intermedius.

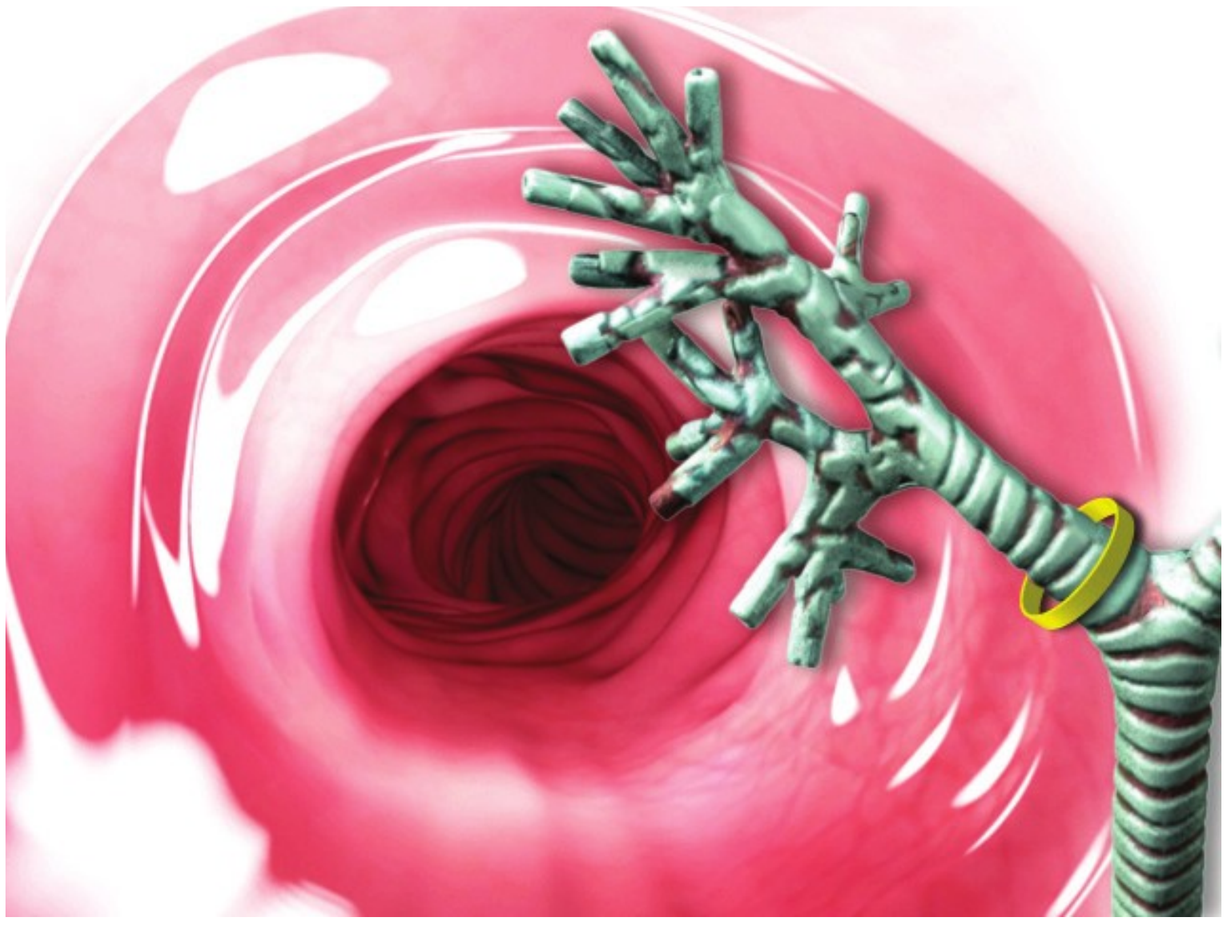


FIGURE 44-5 View of left mainstem bronchus.

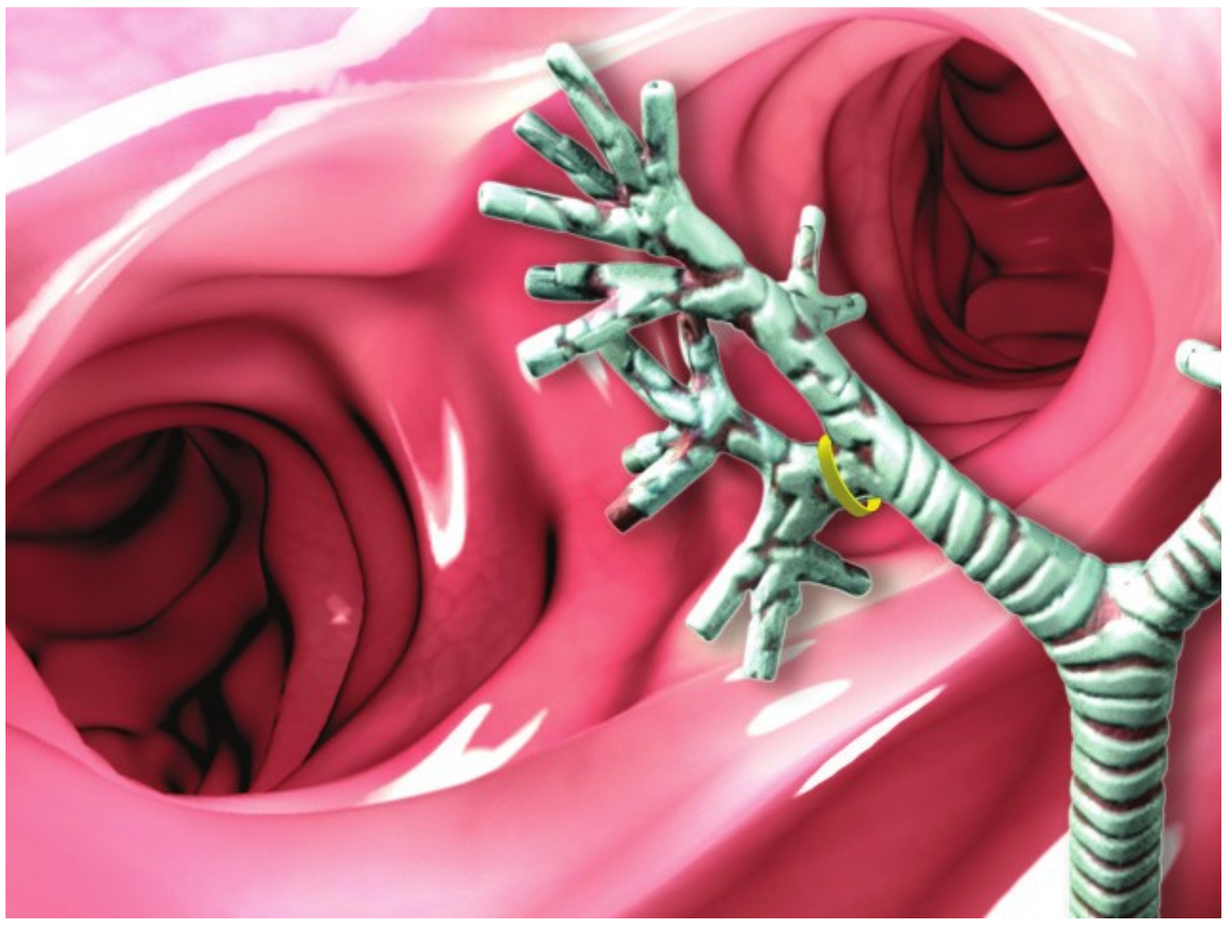


FIGURE 44-6 View of left upper lobe bronchus.

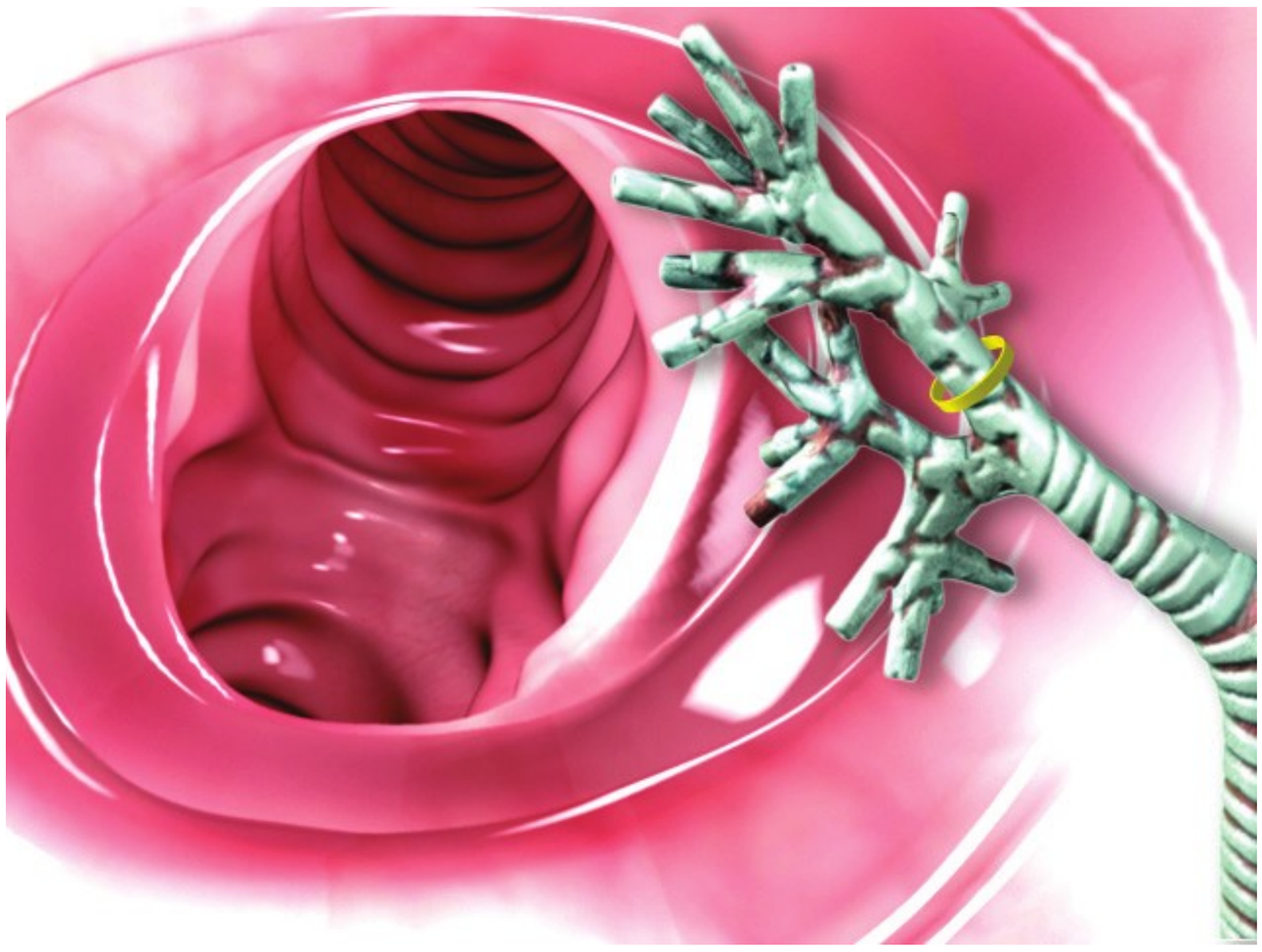


FIGURE 44-7 View of left lower lobe bronchus.

bronchus, the endoscopist enters the right intermediate bronchus, which gives rise to the right middle lobe bronchus and then the right inferior lobe bronchus. The middle lobe bronchus gives rise to segments that comprise the middle lobe of the right lung and the inferior lobe bronchus gives rise to segments that comprise the inferior lobe of the right lung. Understanding this anatomy is essential to locate pathology and to localize endobronchial tube placement.

SEDATION AND PREPARATION

Patients requiring fiberoptic bronchoscopy may present intubated and ventilated, or as outpatients. For those patients who are intubated, a swivel adapter with a port can be attached to the endotracheal tube and the bronchoscopy can be performed while the patient is intubated and ventilated. In some cases, the patient may require significant additional sedation and/or muscle relaxation to perform the bronchoscopy without discomfort to the patient and without coughing during the procedure.

If the patient is not intubated, the airway must be anesthetized, sedation administered, and supplemental oxygen administered. There are several ways to anesthetize the airway. The author's preference is to apply 5% lidocaine cream to a tongue depressor and place the cream and tongue depressor on the patient's tongue. The cream is allowed to melt into the mouth and hypopharynx with subsequent anesthesia to these structures. Once this is accomplished, 4 mL of 2% lidocaine with 0.4 mg glycopyrrolate is administered to the patient via a nebulizer. The lidocaine anesthetizes the epiglottis, glottis, and trachea. The glycopyrrolate dries secretions. After these maneuvers are accomplished, the patient is sedated with fentanyl, midazolam, and dexmedetomidine while supplemental oxygen is administered. Typical doses are 50 to 100 mcg of fentanyl, 1 to 2 mg of Versed, and 20 to 40 mcg of dexmedetomidine. Some patients who are tolerant to these drugs or who are extremely anxious may require higher doses.

Once sedation is complete, the patient should be asked to open his mouth, and the practitioner should use a tongue depressor to ensure that the hypopharynx is numb and that pressure in the hypopharynx does not produce a significant gag reflex. If the patient has a significant gag reflex, additional sedation or topical anesthesia is warranted. In this setting, some practitioners choose to anesthetize the IXth cranial nerve with topical application or bilateral injections of lidocaine near the tonsillar fossae. Other practitioners choose to anesthetize the superior laryngeal nerves with bilateral subcutaneous injections of local anesthetic near the hyoid bone (see Chapter 8).

PROCEDURE

After the above maneuvers, the practitioner may wish to place an Ovassapian airway in the patient's mouth. This device opens the hypopharynx and guides the fiberscope toward the glottis. The fiberscope lens is then cleansed with defogging solution and the fiberscope is advanced into the hypopharynx. If the patient is uncomfortable during this procedure, additional local anesthetic may be administered through the bronchoscope channel. During the bronchoscopy, some practitioners prefer to remove secretions by suctioning through the fiberscope port. Other practitioners prefer to insufflate oxygen through the

fiberscope port and blow the secretions out of the way. Biopsies may be performed through the bronchoscope port. In most cases, the whole procedure (from glottis to segmental bronchi) can be performed in a few minutes once the airway is prepared.

COMPLICATIONS

Complications with this procedure are rare unless biopsies are performed. In the case of biopsy, bleeding and/or pneumothorax may occur. In addition, when bronchoscopy is performed in the patient on mechanical ventilation, the bronchoscope is passed through the endotracheal tube creating the risk of several other complications. These include high peak inspiratory pressures with the potential for barotrauma, and reduced or ineffective tidal volumes, leading to hypoventilation and hypoxemia. As with any cause of resistance to airflow, air-trapping may occur. Careful hand ventilation with lower tidal volumes, reduced inspiratory flow rates, higher FiO_2, and preservation of adequate time for exhalation, should minimize these risks in the intubated patient. Continuous monitoring of vital signs and respiratory parameters throughout the bronchoscopy will likewise contribute to a safe procedure.

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PART XIII

Surgical Situations Requiring Specialized Airway Management

CHAPTER 45

Double-Lumen Endotracheal Tubes

William Ehrman and Theresa Gelzinis

Concept

Double-lumen endotracheal (tracheobronchial) tubes (DLTs) are used in surgeries in which lung isolation is essential. This includes situations in which it is essential to prevent secretions and blood from one lung contaminating the other and when one-lung ventilation (OLV) is desired. Among the techniques used in OLV, which include bronchial blockers (BBs) and single-lumen endotracheal tubes (ETTs)/endobronchial tubes, DLT are the most popular.

The first DLT was the Carlens tube, developed and first used in 1950. The feat ures of this tube included a small internal diameter and a carinal hook, designed to prevent distal migration of the tube (Fig. 45-1). The major disadvantages of the Carlens tube are the small internal diameter of the tube, which produced high resistance to gas flow and precluded effective suctioning, and also the carinal hook, which made it difficult to place through the glottic opening. Robertshaw introduced a red rubber DLT in the 1960s, which lacked the carinal hook and had a larger lumen. Both the Carlens tube and the Robertshaw design were made in both right- and left-sided versions.

The DLTs in current use are made primarily of polyvinyl chloride and are disposable. The DLT consists essentially of one long endobronchial tube fused to a shorter ETT. The distal end of the DLT has two high-volume, low-pressure cuffs in order to facilitate lung isolation. When the tube is properly placed, one cuff is located in the trachea while the other is positioned in either the right or left mainstem bronchus. The endobronchial cuff is blue in color for better visualization during fiberoptic bronchoscopy. These tubes are curved to facilitate guidance into either the right or left mainstem bronchus. The available types of DLTs are manufactured by Covidien, Mansfiled, MA, USA (Mallinckrodt), Smiths Medical, Dublin, OH, USA (Portex), and Teleflex Medical, Research Triangle Park, NC, USA (Rusch and Sheridan) (Fig. 45-2).

Based on the different anatomy of the right and left lungs, both right and left DLT are available. The left main bronchus has a smaller diameter, diverges from the trachea at an angle of 45°, and divides to form upper and lower lobe branches. On the other hand, the right mainstem bronchus branches off the trachea at a less acute angle, is wider than the left bronchus, and forms three lobes (upper, middle, lower). The left bronchus divides into upper and middle lobes approximately 5 to 6 cm away from the carina in women and between 6 and 8 cm in men. The takeoff of the upper lobe of the right lung, however, averages approximately 1 to 2 cm below the carina, necessitating specialized right double-lumen tubes that allow the right upper lobe (RUL) to be ventilated.[1] The endobronchial cuff is uniquely designed on right-sided double-lumen tubes in order to prevent obstruction of the RUL. The design of the endobronchial cuff for these right-sided DLTs, which provides isolation with a "slot" in order to ventilate the RUL, varies among manufacturers (Fig. 45-3). Some right-sided DLT also have a radiographic white marker, which facilitates placement with a fiberoptic bronchoscope (FOB).

Placement of the DLT can be challenging. Alliaume et al studied the number of DLTs that required repositioning with FOB after being inserted blindly in 24 patients. Blind insertion resulted in 78% malpositioning of left-sided DLTs and 83% of right-sided DLTs, such that FOB was necessary to adjust the position of the tube.[2] Klein et al[3] showed that of 200 DLTs that were placed blindly, 35% were not correctly positioned when fiberoptic bronchoscopy was used to confirm placement. A study by Boucek et al[4] showed that when comparing the blind technique with the direct vision technique for left-sided DLT insertion, both methods were successful, but more time was required using fiberoptic bronchoscopy compared with the blind technique (88 vs 181 seconds, respectively).

Evidence

When comparing DLTs with the other methods of lung separation and OLV, DLTs have several distinct advantages and are considered the best tool for absolute lung

FIGURE 45-1 Carlens design Rusch DLT.

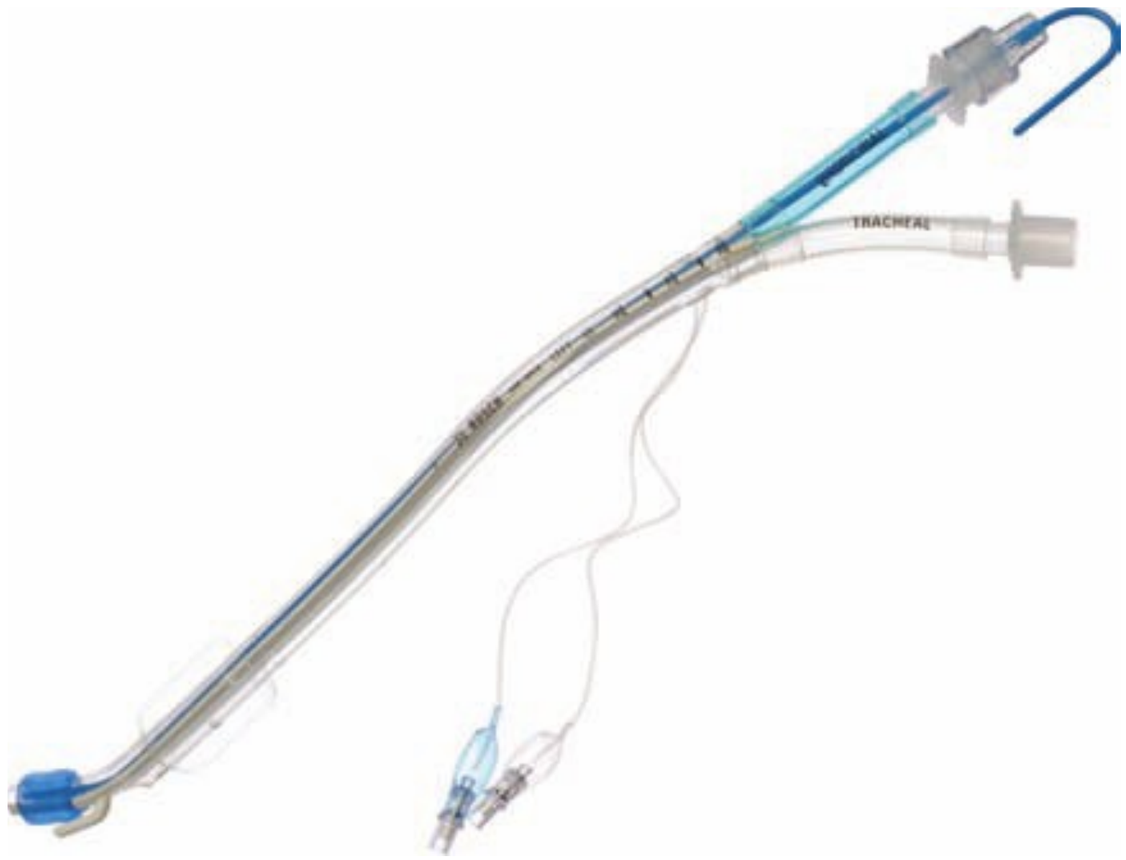
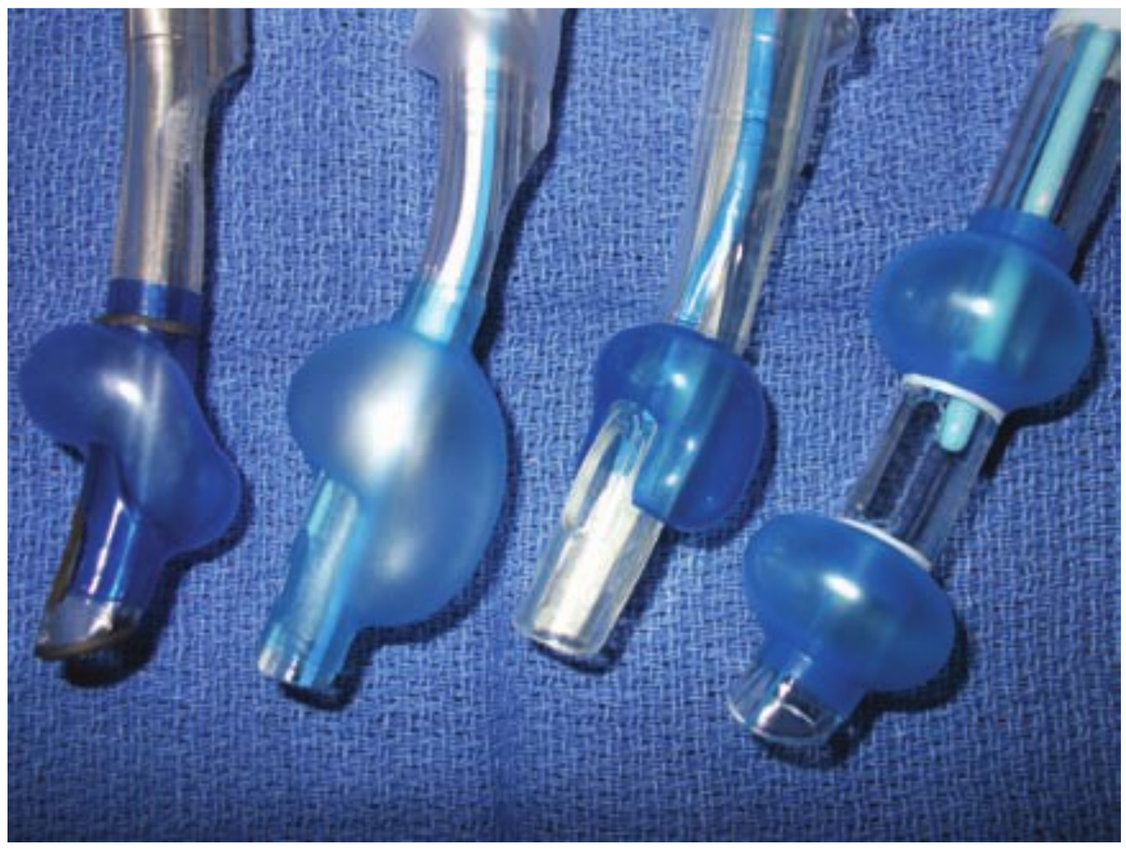


FIGURE 45-2 Left-sided DLTs from left to right: Mallinckrodt, Portex, Rusch, and Sheridan.



FIGURE 45-3 Endobronchial cuffs of right-sided double-lumen endobronchial tubes from left to right: Mallinckrodt, Portex, Rusch, and Sheridan.



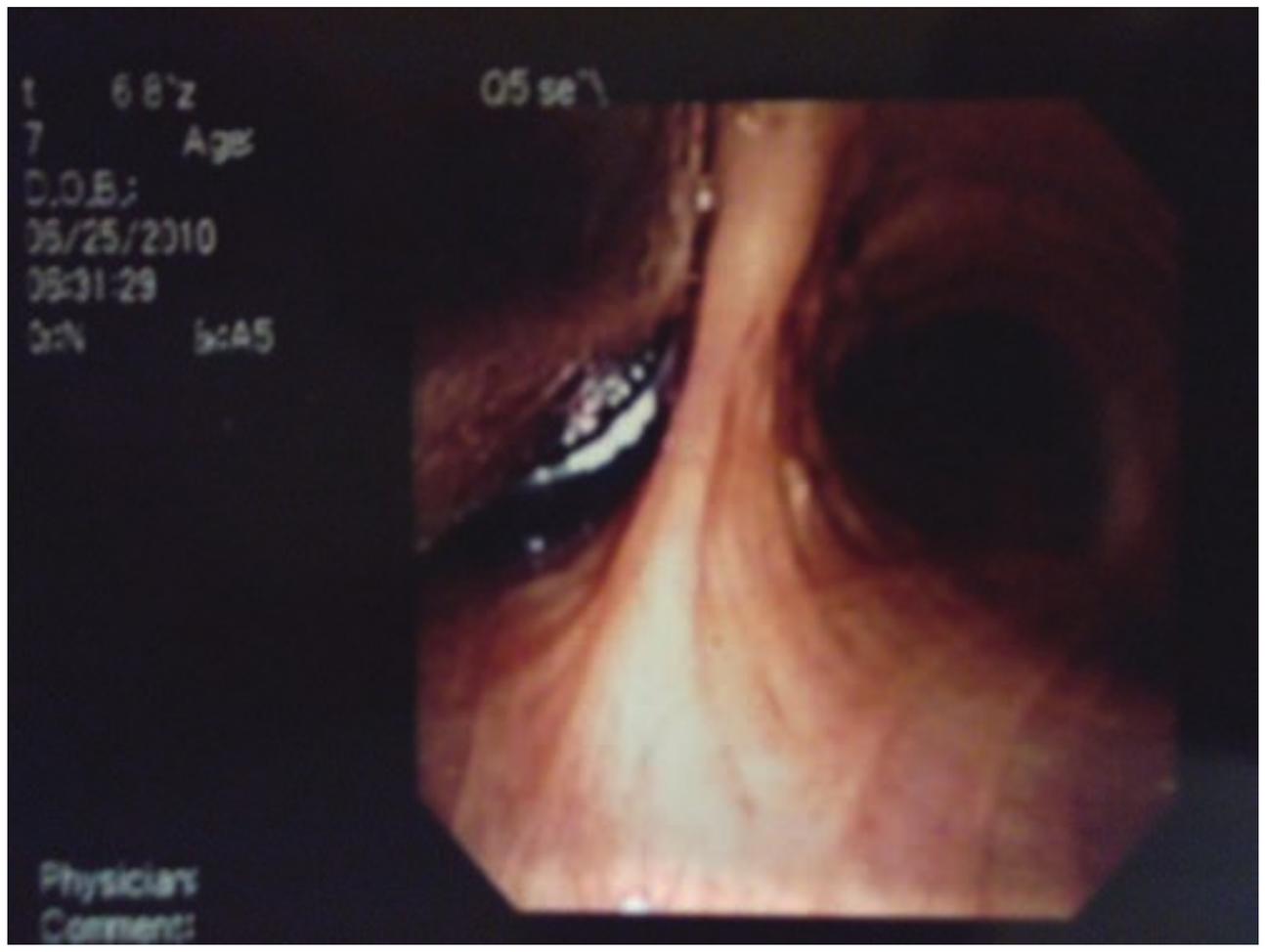


FIGURE 45-4 Fiberoptic view of the carina and the correct positioning of a left-sided DLT in the left mainstem bronchus with the blue endobronchial cuff inflated.

isolation. Either lung can be isolated and ventilated independently without having to move either a right- or left-sided DLT. The DLTs have an internal diameter that is able to accommodate either an FOB or suction catheter through both the tracheal and bronchial lumens, which facilitates visualization and suctioning of each lung.

A study by Narayanaswamy et al compared DLTs with BBs during thoracic surgery, measuring the time it took each to isolate the left lung, the number of times each had to be repositioned, and the mean peak airway pressures generated by each device.[5] The time for lung isolation was significantly less for DLTs versus BBs (93 ± 62 vs 203 ± 132 seconds). Also, double-lumen tubes had to be repositioned far fewer times than the BBs (2 vs 35). With regard to peak airway pressures, not only did DLTs have lower mean values (16 cm H_2O vs 19 cm H_2O), but patients being ventilated with BBs had a lower pH and higher $PaCO_2$ compared with DLTs.

Double-lumen tubes are the better choice in cases where lung separation is absolutely necessary, as well as for sleeve pneumonectomies. BBs are more advantageous when a patient presents with an anticipated difficult airway, if nasal intubation is necessary, if the patient has an established ETT and is too unstable to change to a DLT, and also when the patient will require postoperative mechanical ventilation-especially with a right-sided DLT.[6]

Double-lumen endobronchial tubes have also been shown to cause more trauma to the airway, increasing the incidence of postoperative hoarseness and throat pain. A review of DLTs over 25 years was conducted by Fitzmaurice et al,[7] who found that airway injuries were more common with undersized DLTs, and bronchial rupture was more common with disposable, polyvinylchloride DLTs. Heike studied the incidence of postoperative hoarseness and sore throat, as well as using bronchoscopy immediately following the surgery in order to objectively assess vocal cord and bronchial injuries in a population undergoing thoracic surgery. Patients experienced significantly more hoarseness in the DLT group compared with the bronchial blocker group (44% vs 17%). Postoperative vocal cord lesions were also increased in patients in the DLT group (44% vs 17%), whereas the incidence of bronchial lesions were similar between the two groups.[8]

Some controversy exists in comparing the use of right- and left-sided DLTs. Due to the narrow margin for error when inserting a right-sided DLT and during repositioning of the patient (due to obstruction of the RUL bronchus), opponents of these devices state that the only situations in which right-sided DLTs should be used in clinical practice are when there is an intrinsic or extrinsic left mediastinal, thoracic, or bronchial mass that prevents the insertion of a left-sided DLT, and for teaching purposes. Cohen[9] has noted that there is a steep learning curve when training to use the right-sided DLTs because there are different shapes and locations of the endobronchial cuffs and different sizes among the ventilation slots between manufacturers. Fiberoptic bronchoscopy is essential when using a right-sided DLT, both during insertion and throughout the case because the margin of error is only 1 to 8 mm for right-sided DLT compared with 4 to 6 cm when using a left-sided DLT.[1] Campos et al[10] found that the time required for correct placement was almost double than the left-sided DLT. Finally, if postoperative mechanical ventilation is required, a right-sided DLT must be exchanged for a single-lumen ETT because the intensive care unit staff does not have the training to manage a right-sided DLT if it should become improperly positioned. Of concern, when exchanging ETTs, the dependent lung may

become exposed to blood and secretions, or a difficult reintubation may be encountered because of the postoperative edema, blood, and secretions.[9]

The only contraindication in the use of the right-sided DLT is an anomalous takeoff of the RUL bronchus directly from the trachea, which occurs in approximately 1 in 250 patients.[11] With recent improvement in the design of right-sided double-lumen tubes and in the techniques used for placement, there are several investigations that have shown that right-sided DLTs have similar efficacy and safety when compared with BBs and left-sided DLTs.[10,12] Ehrenfeld et al retrospectively compared the incidence of these outcome measures between right- and left-sided DLTs when inserted by anesthesiology residents under supervision. They found that there was no clinically important difference in the incidence and duration of hypoxemia, hypercapnia, and high inspiratory airway pressures when right-sided DLTs were used compared with left-sided DLTs by infrequent users. In fact, the duration of hypoxemia and the frequency of hypercapnia and increased airway pressures were greater for left DLTs compared with right DLTs.[13]

Right-sided DLTs are more advantageous for certain surgical procedures. For a left-sided pneumonectomy, right-sided DLTs are the more practical choice to provide OLV. Compared with the left-sided DLT, the right-sided DLT does not have to be withdrawn from the left bronchus, exposing the dependent lung to blood and secretions.[14]

Sizing

Compared with single-lumen ETTs, DLTs require more meticulous sizing, accuracy of placement, and knowledge of the tracheobronchial tree on a case-to-case basis. Table 45-1 shows a rough estimate of DLT size based on sex and height. However, differences in both individual anatomy and between double-lumen tubes makes sizing DLTs for each case more difficult. Both CT scans and chest X-rays should be reviewed prior to the placement of the DLTs in order to identify abnormalities in the tracheobronchial tree. CT scans can be used to determine the width of the main bronchus, whereas the length of the bronchus can be measured using chest X-rays. Benumof et al[1] determined that the length of the left main bronchus varies between 27 and 68 mm. A standard chest X-ray magnified the main bronchus approximately 9% in both length and diameter.[15] Also, in patients where the bronchi were not visualized on chest X-ray, Brodsky and Lemmens[16] determined that the left bronchial width was approximately 68% of the tracheal width.

Chow et al demonstrated that the depth of insertion of DLTs correlates with patient height. They determined that the average depth for insertion of a left-sided DLT was 29 cm for adults 170 to 180 cm tall. For every 10-cm increase or decrease in height, the DLT was advanced or withdrawn 1 cm, respectively.[17]

When comparing DLTs of the same size between manufacturers as well as those of the same manufacturer, Partridge and Russell found that there was a 19 to 40 mm difference in the distance from the proximal bronchial cuff and the tip of the bronchial tube. This length must be less than the length of the left main stem bronchus, which originates at the carina and ends at the takeoff of the left upper lobe, in order to prevent occlusion at the carina or of the left upper lobe bronchus. Therefore, at least a 10-mm margin of safety is suggested between the cuff-tip length of the DLT and the length of the left main bronchus.[18] If the dimensions of the left bronchus are known, and a DLT is specifically selected so that the margin of safety is large, studies have shown that confirming the DLT placement with a FOB after blind insertion is unnecessary.[19]

Table 45-1

Estimation of DLT Size Based on Sex and Height

Adult Sex	Height (in)	DLT Size (Fr)
Female	<60	32
	60< × <63	35
	>63	37
Male	<63	37
	63< × <67	39
	>67	41

Data from Slinger PD, Campos JH. Anesthesia for thoracic surgery. In: Miller RD, ed. *Miller's Anesthes*ia. 7th ed. St. Louis, MO: Churchill Livingstone, 2009, with permission.[24]

Preparation

- Standard preparations for direct laryngoscopy (Chapter 5) and fiberoptic bronchoscopy (Chapter 23)
- Check both the 20 cc tracheal cuff and the 3 cc bronchial cuff prior to use

Placement

Blind technique for left DLT placement

- Standard technique for direct laryngoscopy (Chapter 5)
- Curved (Macintosh) blades allow the best visualization and greatest area to pass the DLT

- The DLT is initially inserted with the concave curvature facing anteriorly
- Once the DLT is through the vocal cords, the DLT is rotated 90° counterclockwise if left main bronchus placement is desired and rotated 90° clockwise if placement into the right main bronchus is the goal
- Remove the stylet
- Advance the tube until resistance is felt
- Proceed to confirmation section below

Alternate blind technique for left DLT placement[20]

- Standard technique for direct laryngoscopy (Chapter 5)
- The DLT is initially inserted with the concave curvature facing anteriorly
- DLT is passed through the vocal cords and advanced into the mid trachea
- The bronchial cuff is over inflated to occlude the trachea
- Connect the circuit to the bronchial luman of the DLT
- Confirmation that both lungs are being ventilated
- While ventilating, the DLT is advanced slowly 1 cm at a time until one lung is being ventilated, which confirms the cuff is occluding the bronchus at the carina. The cuff remains inflated during this tube advancement
- If the left lung is being ventilated, the cuff is deflated and the DLT is advanced 1 cm
- If the right lung is being ventilated, note the depth because this is the distance to the carina. Initially attempt to deflate the cuff, withdraw and reinsert the DLT. Check to confirm left bronchus intubation. If the DLT remains in the right bronchus, deflate the cuff, withdraw the bronchial cuff, rotate the patient's head to align the chin with the right shoulder, and rotate the long axis of the DLT 90° counterclockwise. Inflate the bronchial cuff and advance the DLT while ventilating the patient until the left lung is the only lung being ventilated. Deflate the bronchial cuff and advance the DLT 1 cm
- Reinflate the bronchial cuff with 1 to 2 cc of air
- Check with FOB to confirm adequate margin of safety (see *Sizing* section above)
- Proceed to confirmation section below

Direct vision for placement of right-sided DLT

- Standard technique for direct laryngoscopy (Chapter 5)
- Direct laryngoscopy until the DLT is through the vocal cords
- FOB is inserted through the endobronchial lumen, directing the DLT into the left mainstem bronchus (Chapters 23 and 24)

Direct vision for placement of right-sided DLT[10,12]

- Standard technique for direct laryngoscopy (Chapter 5)
- Direct laryngoscopy until the DLT is through the vocal cords
- Remove stylet
- Advance to mid trachea, rotate 90° clockwise
- FOB is inserted through the endobronchial lumen, directing the DLT into the right mainstem bronchus (Chapter 23)
- Identify the RUL ventilation slot
- Align the DLT RUL ventilation slot with the takeoff of the RUL bronchus, rotating, advancing, and withdrawing the DLT as necessary
- Pass the FOB through the RUL ventilation slot to confirm placement
- Inflate bronchial cuff
- Confirm that the bronchial cuff is 2 to 5 mm below the carina in the right mainstem bronchus
- Confirm patency of distal endobronchial lumen using FOB

Confirmation of position of left-sided DLT (Fig. 45-4)

- Auscultation alone is unreliable but can be used as an adjunct (see above section on *Evidence*)
- Once DLT is in position, inflate the tracheal cuff with minimal volume to prevent air leak and confirm bilateral lung ventilation
- Clamp the tracheal lumen proximally, open the port distal to the clamp, ventilate the bronchial lumen, inflating the bronchial cuff until air leak is prevented through the open tracheal port
- Release the tracheal clamp, close tracheal port, auscultate for bilateral breath sounds
- Clamp each lumen selectively to confirm ventilation of the contralateral side and absence of breath sounds on the ipsilateral side
- Confirmation with a FOB is recommended
- With the FOB through the tracheal lumen, check the endobronchial cuff for herniation of the endobronchial cuff over the carina. Figure 45-4 displays the correct position of the cuff of a left-sided DLT
- Check the endobronchial lumen for patency and to confirm the DLT cuff is not too deep, obstructing the left upper lobe or the left lower lobe
- Recheck placement with FOB after both patient and surgical field manipulation to confirm positioning of DLT

Practicality

- Cost: Approximately $50 to $80 each
- Definite learning curve, experience necessary
- FOB experience recommended
- Not recommended for anticipated and unanticipated difficult airway situations

Indications

Absolute

- Isolation of a lung to prevent contamination of the contralateral lung, such as with infection, hemorrhage, unilateral lung lavage
- Ventilation of one lung secondary to bronchopleural and bronchopleural cutaneous fistula, unilateral bulla or cyst, trauma with tracheobronchial disruption, severe lung disease with significant V/Q mismatch

Relative

High indications

- Pneumonectomy, thoracic aortic aneurysm, upper lobectomy, lung volume reduction surgery

Moderate indications

- Video-assisted thoracoscopic surgery to allow for maximal exposure of the surgical field, middle and lower lobectomy, mediastinal surgery, esophageal surgery, thoracic spine surgery

Right-sided DLT

- Distorted anatomy by left bronchus tumor, external tumor compression, or thoracic aortic aneurysm
- Left-sided tracheobronchial resection, left sleeve resection, left lung transplant, left pneumonectomy because withdrawal of a left-sided DLT would increase the possibility of blood contaminating the contralateral lung

Contraindications

- Patient refusal
- Extrinsic or intrinsic obstruction, distorted anatomy
- Patients requiring rapid sequence intubation
- Patients having anticipated difficult airways
- Anomalous takeoff of the RUL bronchus above the carina for right-sided DLTs

Complications

- Failed intubation
- Malposition with inability to collapse isolated lung or partial ventilation of dependent lung secondary to cuff overinflation, surgical field manipulation, change in patient position
- Trauma: Sore throat, hoarseness, tracheal or bronchial tissue necrosis from excessive cuff pressure, tracheal or bronchial rupture/injury from a DLT that is too large or migration of an undersized DLT, barotrauma from migration of an undersized DLT distally out of the mainstem bronchus

Special situations

Difficult Airway (Chapters 9 to 15)[21]

- Use of a DLT over a FOB during an awake intubation in a patient with an anticipated difficult airway (Chapter 23)
- Use of a lighted stylet (Chapter 20) or fiberoptic laryngoscope (Chapter 24)
- Use of an exchange catheter at least 83 cm long

Tracheostomies

- Left-sided 41-F DLT have been developed by Sheridan[22] to accommodate the shorter airway
- Left-sided 39-F, wire-reinforced silicon (Naruke tube, Koken Medical, Tokyo, Japan)[23]

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CHAPTER

46

Bronchial Blockers in Thoracic Surgery

Ali Abdullah and Ibtesam Hilmi

Concept

Two methods are available to achieve one-lung ventilation (OLV), the double-lumen endotracheal tube (DLT) and the bronchial blockers (BBs). Both of them will allow anatomic isolation of the lungs. The absolute indication for OLV is to protect the healthy lung from ipsilateral diseased lung or secretions such as blood, pus, or fluid used for pulmonary lavage (as in alveolar proteinosis). In addition, lung separation is required during bronchopleural fistula to prevent loss of tidal volume, and during resection of giant unilateral bullae. The relative indication for OLV is to provide an optimal and quiet surgical field during various types of thoracic surgeries such as pneumonectomies, repair of thoracic aortic aneurysms, and esophageal surgery.[1] The disadvantages of DLTs are difficulty in achieving the accurate position and size restriction, because they are available in specific sizes only (28, 35, 37, 39, 41), which makes placement difficult in small patients (pediatric population) or in patients with difficult airway anatomy. DLTs require replacement with a single-lumen ET at the end of surgery if the patient requires postoperative ventilation, a procedure that can be complicated and hazardous, especially in patients with difficult airway and/or prolonged surgery resulting in massive fluid shifts with airway edema.[2]

BBs may be used to provide lung isolation in conjunction with single-lumen endotracheal tube (ETT), eliminating the requirement to change the ETT at the end of the procedure. BBs are especially indicated in patients with difficult airway or abnormal airway (postsurgery or postradiation) or during prolonged surgery with large-scale fluid shifts resulting in airway edema, as well as in patients who are already are intubated with single-lumen ETT before coming to surgery. BBs may be placed through or alongside the single-lumen ETT, and a 7.0-mm ETT can easily allow the passage of a 4.0 fiberoptic bronchoscope with a BB.[1] The following are the most commonly used types of BBs:

1. Fogarty embolectomy catheter (no. 7.0) (Edwards Lifesciences, Irvine, CA, USA) with the occlusion balloon (size 5.0 to 8.0 mL).
2. Wire-guided endobronchial blocker (Arndt blocker, Cook Critical Care, Bloomington, IN, USA).
3. Single-lumen tube with an incorporated BB (Univent, Vitaid Ltd., Lewiston, NY, USA).

Evidence

There is scant evidence supporting one method of OLV as clearly superior to the other, so it is ultimately left to the anesthesiologist to select which method of OLV he/she is comfortable with (See also chapter 45). The practitioner must understand the fundamental advantages and disadvantages of each technique in various circumstances, to assure the optimal use and the least possible intra-/postoperative complications. In a study conducted by Campos and Kernstine[3] in 2003, the authors demonstrated that not only did DLT intubation require less time to place but also lung collapse was accomplished significantly faster than BBs (DLT took an average of 2:08 minutes as compared with 3:34 minutes for the Arndt blocker). However, the ability to use BBs across a wide range of patient populations makes these devices increasingly popular and practical devices.

Preparations

- Anesthetized, intubated patient in neutral position
- Preparation of the fiberoptic bronchoscope
- Preparation of the Univent tube or Arndt blocker

Procedure for Arndt blocker or Fogarty catheter placement (Figs. 46-1–46-3)

- Induce general anesthesia with muscle relaxation
- Intubate the patient with appropriate size single-lumen ETT
- Connect the Arndt blocker connecter to the ETT (Fig. 46-1)
- Maintain anesthesia and ventilation through the side port of the connecter that should be hooked up to the anesthesia circuit (Fig. 46-1)
- Pass the bronchoscope through the designated port (Fig. 46-1) and hook up the blocker to the bronchoscope using the snared wire (Fig. 46-2)

- Pass the bronchoscope and the attached blocker into the mainstem bronchus that is to be blocked (Fig. 46-3)
- The same procedure may be applied to insert a Fogarty catheter

Procedure for Univent tube placement (Figs. 46-4–46-7)

- Induce general anesthesia with muscle relaxation
- Intubate the patient using the appropriate size of Univent tube
- Pass the fiberoptic bronchoscope through the side port (Fig. 46-4)
- Use the bronchoscope to advance the blocker through the mainstem bronchus to be blocked (Fig. 46-5)
- Inflate the blocker's cuff and pull out the bronchoscope (Figs. 46-6 and 46-7)

Practicality

- The procedure requires proficiency in handling the fiberoptic bronchoscope. Patients may be kept adequately ventilated through a different port without affecting the progress of the blocker insertion

Indications

Apart from providing lung isolation, these devices are helpful in the following situations related to thoracic surgery:

- When postoperative ventilation is required in patients with difficult airway, prolonged surgery with massive fluid shift
- Univent or BBs can be used in small patients and in pediatric population; BBs can be inserted alongside the ETT or inside the ETT
- In patients who are already intubated (intensive care unit patients) before the surgical procedure

Advantages

1. No need to change the ETT from double lumen to single lumen at the end of the procedure
2. Continuous positive airway pressure and suction can be applied through the BB tube, though not through a Fogarty catheter

Disadvantages

1. Large external diameter of the Univent tube makes it hard to pass through the vocal cords.
2. Possible to injury to the bronchus by the stiff BBs.
3. The relatively small internal diameter of the BBs makes it difficult to provide adequate oxygenation (with the blocker alone) or suctioning of the pulmonary secretion. The Fogarty catheter is not designed to function as BBs, and when the internal guidewire is pulled out after the insertion, it is impossible to reinsert the wire if repositioning is required for the BBs. Also, due to the tiny internal diameter, it is almost impossible to provide suction or oxygenation.



FIGURE 46-1 Loading the Arndt BB.

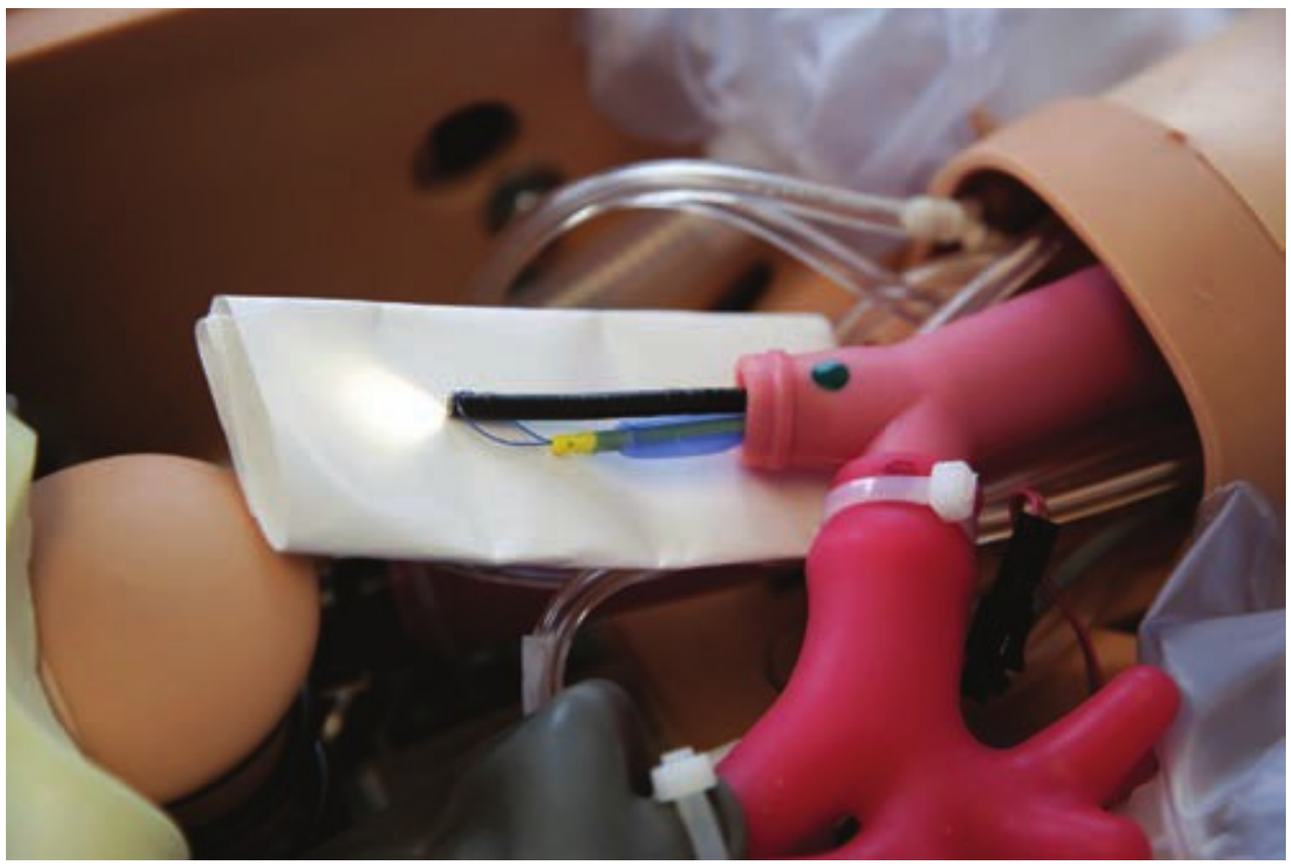


FIGURE 46-2 The bronchoscope and the Arndt blocker in the right mainstem bronchus of an intubating mannequin.

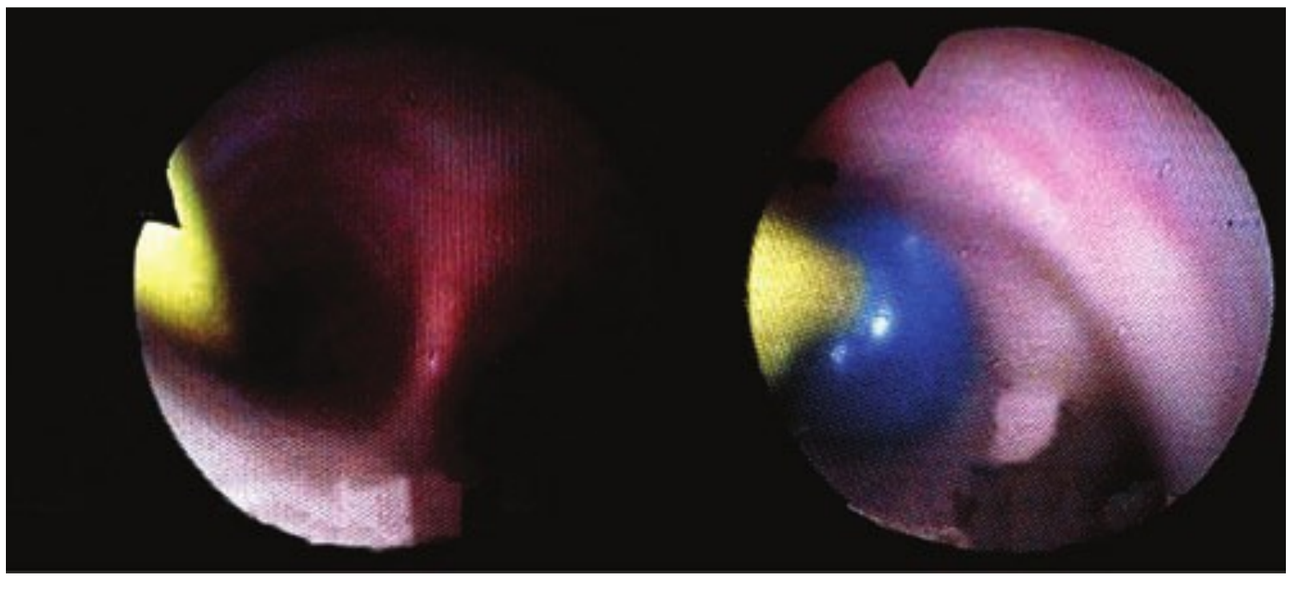


FIGURE 46-3 The Arndt blocker placed in the mannikin's left mainstem bronchus.

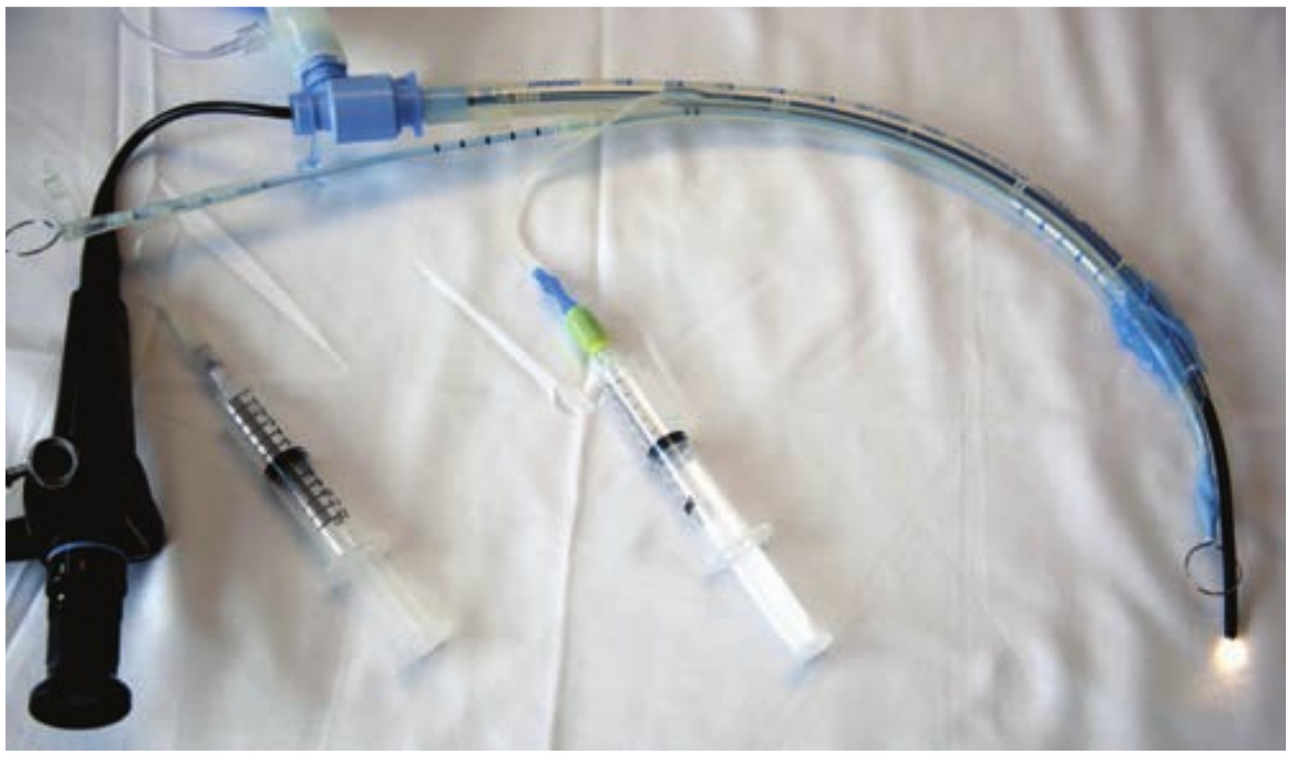


FIGURE 46-4 Loading the Univent tube.



FIGURE 46-5 Univent tube in place.

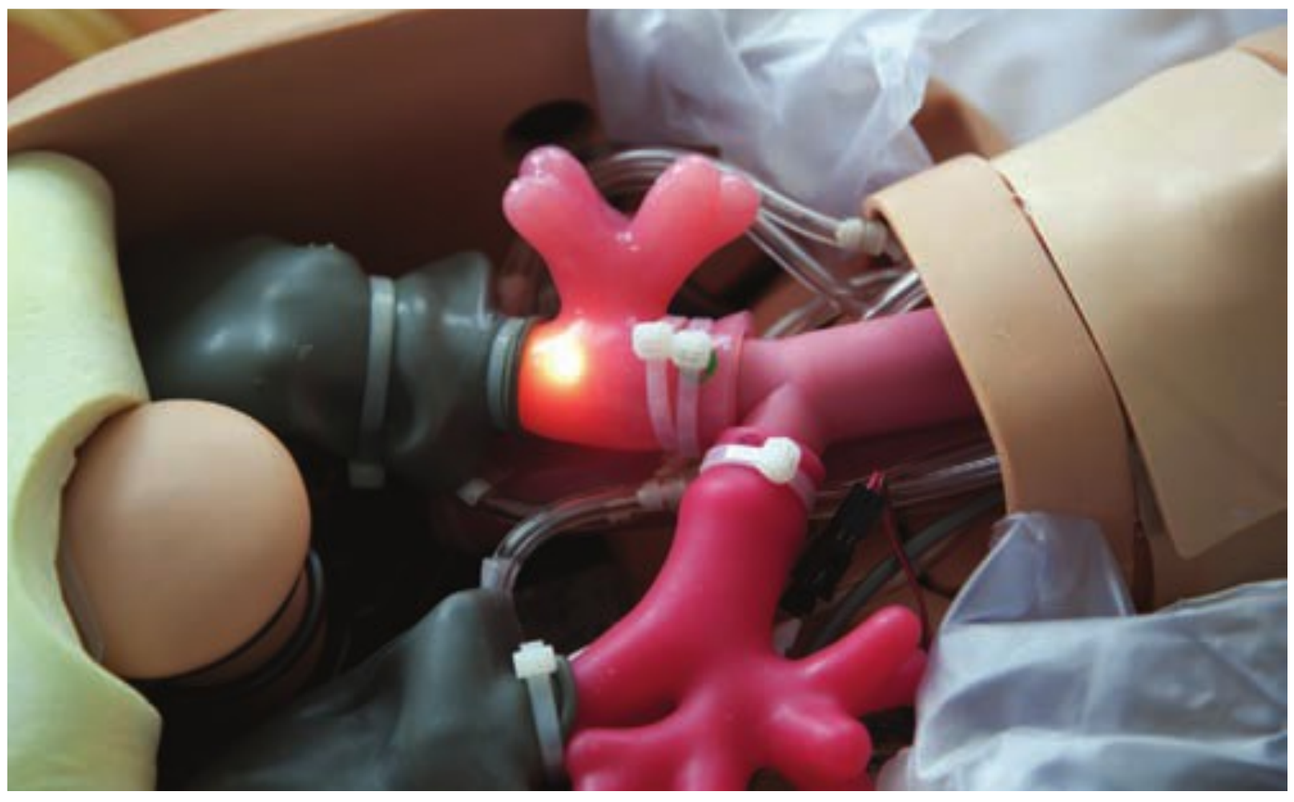


FIGURE 46-6 Fiberoptic bronchoscope with the Univent tube blocker placed in the mainstem bronchus.



FIGURE 46-7 Fiberoptic bronchoscope snared to the Univent blocker and placed in the right mainstem bronchus.

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CHAPTER 47

Laser Airway Surgery

Adam P. Childers and Patrick J. Forte

Concept

Laser airway surgery requires the provision of safe and appropriate anesthesia, while at the same time providing the surgeon with the best possible exposure and surgical field conditions. Airway management in these cases should be a collaborative effort between the anesthesiologist and the surgeon to ensure a positive outcome for the patient. In this setting, the anesthesiologist must balance the preservation of adequate gas exchange with visualization and surgical access while minimizing the risk for airway damage from fire and direct or indirect laser contact. The choice of airway management technique depends upon several factors, including the indication for and site of the surgery, the type of laser used, the anesthesiologist's level of comfort with the techniques, and the equipment available at the surgery location. The techniques available for airway management to maintain adequate ventilation and anesthesia during laser airway surgery include intubation of the trachea, both rigid and flexible bronchoscopy, jet ventilation, intermittent apnea, and spontaneous ventilation by the patient throughout the procedure.

The choice of a specific airway management technique depends on multiple determinants, one of which is the surgical site. Laser surgery in the nose and nasopharynx can be accomplished with a traditional oral endotracheal tube. The tube does not necessarily have to be a specific laser tube if the tube is not in the laser field. The oropharynx should be packed with saline-soaked gauze during such a procedure. Laser surgery in the oropharynx requires laser-safe endotracheal tubes.

When lasers are used for laryngeal surgery, the size of the lesion is of particular importance in determining the airway management technique. For small, nonobstructing lesions of the larynx, a laser-safe tube with saline-soaked gauze in proximity to the surgical site is acceptable. For lesions of the posterior larynx, a tubeless or intermittent apnea technique is desirable. Perhaps the most challenging situation is the obstructing, malignant tumor of the larynx. For this, communication between the surgeon and the anesthesiologist is critical, as these patients may present a difficult intubation, and airway management interventions differ widely on a case-by-case basis. In general, the smallest practical laser-safe tube should be used. Alternatively, intermittent apnea with total intravenous anesthesia (TIVA)is a possibility. Jet ventilation, either via the surgical laryngoscope, rigid bronchoscope, or transtracheally, is another option. For laser surgery involving a tracheostomy, a laser-safe endotracheal tube replacing the tracheostomy tube or metal tracheostomy tube can be used. Laser surgery involving the bronchial tree can be accomplished with jet ventilation via rigid bronchoscopy.

Intubation Technique

Direct laryngoscopy and various adjuncts mentioned in other chapters can be used for placing an endotracheal tube for laser surgery. The choice of an endotracheal tube is based on multiple factors. Polyvinyl chloride (PVC) tubes are inexpensive and nonreflective but have a low melting point and are highly combustible. Red rubber tubes are puncture resistant, nonreflective, and can maintain structure, but unfortunately they are highly combustible. Silicone rubber tubes are nonreflective but combustible. Metal endotracheal tubes are combustion-resistant and kink-resistant, but often have thick walls, are not as easy to maneuver, and can reflect the laser and transfer heat.[1] Figures. 47-1 and 47-2 show a Mallinckrodt Laser-Flex (Covidien, Mansfield, MA) endotracheal tube being used for microsuspension laryngoscopy and carbon dioxide (CO_2) laser removal of a vocal cord lesion.

Endotracheal Tubes

There are numerous brands of endotracheal tubes with different compositions on the market.

Mallinckrodt Laser-Flex endotracheal tubes have a corrugated stainless steel shaft with a PVC adapter. These tubes have two PVC cuffs on the adult tubes with two separate pilot tubes that run along the inside of the tube (Fig. 47-3). These tubes are for use with CO_2 and potassium titanyl phosphate (KTP) lasers. There are also cuffless versions of this tube available as well (Fig. 47-4).[2]

Lasertubus (Rusch, Duluth, GA) is composed of a soft white rubber shaft that is covered with a silver foil and a Merocel sponge. It also has a double cuff. An advantage is that it can be used with all lasers.[3] However, this tube is subject to crimping.[4]

Norton (A.V. Mueller, Niles, IL) laser endotracheal tubes are cuffless, spiral-wound, stainless steel tubes with a sandblasted finish. They tubes have a thicker wall and can create an obstruction of the view. Although these tubes are no longer manufactured, they may still be in use in some institutions because they are reusable. These tubes are resistant to CO_2, neodymium:yttrium-aluminum-garnet (Nd:YAG), and KTP lasers. This tube is the best option for upper airway laser surgery with an neodymium:yttrium-aluminum-garnet (Nd:YAG) laser.[5]

Xomed Laser-Shield II (Medtronic ENT Surgical Products Inc., Jacksonville, FL) endotracheal tubes are silicon rubber tubes that have an aluminum foil tape wrapping for laser protection in addition to a Teflon cover to give it a smoother surface as compared with the earlier Xomed Laser-Shield I (Xomed-Trence, Jacksonville, FL). However, neither end of the tube is laser resistant. These are for use with CO_2 or KTP lasers only, and are contraindicated with Nd:YAG or argon lasers.[6,7]

Sheridan Laser-Trach (Hudson RCI, Research Triangle Park, NC) endotracheal tubes are red rubber tubes with an outer copper foil, which is covered by an outer absorbent fabric that creates a smooth exterior surface. It is to be used with CO_2 and KTP lasers only.[8]

Xomed Laser-Shield I and Bivona Laser endotracheal tubes (Bivona, Gary, IN) are not recommended for use.[9,10]

Adjuncts to Endotracheal Tubes

Metallic foil tapes can be used as a layer of protection around an endotracheal tube. These tapes only protect against the direct impact of a laser upon a combustible tube. There is still a risk of indirect combustion. The presence of blood on the tape can decrease the combustion time. Venture copper foil tape (Venture Tape Corporation, Rockland, MA) or 3M 425 tape (3M, St. Paul, MN) or 3M 425 tape is recommended for CO_2 lasers,[11] whereas only 3M 425 tape is recommended for Nd:YAG lasers.[12] It is important to note both the brand and model number of the tape if used, because there are several different lines marketed by each manufacturer. There are disadvantages to wrapping endotracheal tubes. Wrapping offers no cuff protection and adds thickness to the tube. The protection afforded differs with each type and brand of material, and the adhesives can ignite if exposed. In addition, there may be mucosal injury from the edges of the wrap. A Merocel Laser-Guard ET protector (Merocel, Mystic, CT) is useful for CO_2, Nd:YAG, and KTP lasers. It is an adhesive silver foil with a sponge coating. This sponge coating must be kept moist with saline.[13]

Saline-filled cuffs on endotracheal tubes add the benefit of significantly slower deflation times in the event of perforation by the laser. The incidence of perforation is the same as air-filled cuffs; however, the saline extinguishes any nidus for ignition.[14,15] Often times, the cuff is filled with methylene blue solution so that a perforation may be recognized quickly, as shown in Figs. 47-5 and 47-6.

Aluminum foil is often used to wrap the anesthesia circuit, from its attachment to the endotracheal tube, well back from the surgical field, in order to prevent inadvertent ignition from a wayward laser (Fig. 47-7).

Bronchoscopy[2]

Rigid bronchoscopy is an option for laser surgery involving the trachea, carina, and mainstem bronchi. Through the bronchoscope, the anesthesia delivery system can be attached and ventilation and anesthesia can be maintained. The rigid bronchoscope is larger than a flexible bronchoscope and provides working channels on its side; however, because of its size and almost complete obstruction of the airway, general anesthesia must be used, as opposed to sedation that may be used with the flexible scopes. Flexible bronchoscopy offers the advantage of providing easier access to distal airway lesions.

Jet Ventilation[2]

Jet ventilation consists of using a cannula, needle, or other similar device that can be positioned on a surgical laryngoscope, rigid bronchoscope, or may be placed transtracheally. High-frequency jet ventilation or Venturi jet ventilation may be used, depending on the indication for surgery and location of the airway lesion. Maintenance anesthesia in these circumstances must be accomplished with intravenous agents. High-frequency jet ventilation with small tidal volumes provides excellent views of the surgical field with minimal movement caused by respiratory mechanics, allowing for better precision with the laser. The alignment of the jet ventilation cannula is critical, as misdirection can lead to decreased ventilation, increased air in the gastrointestinal tract, or barotrauma leading to possible pneumothorax or pneumomediastinum. This technique is not useful when the compliance of the lungs is poor or when the larynx is obstructed.

Intermittent Apnea[16]

Intermittent apnea involves tracheal intubation, extubation, and reintubation during TIVA. The patient's trachea is initially intubated following the induction of general anesthesia. Once TIVA is established, the patient breathes 100% O_2, and when the surgeon is ready, the trachea is extubated. The surgeon then performs as much of the operation as possible until the patient begins to show a decline in oxygen saturation, at which time the trachea is

reintubated (usually by the surgeon under direct vision), and all surgical interventions are paused until the patient's oxygen saturation returns to normal. This process can then be repeated as many times as necessary to complete the procedure. Alternatively, the patient's lungs can be ventilated with a mask instead of endotracheal intubation. This technique is only suitable for skilled surgeons and anesthesiologists and for relatively short procedures.

Spontaneous Breathing Technique

Using a surgical laryngoscope with a side oxygen insufflation port, laser surgery can be accomplished with the patient spontaneously breathing. Induction of anesthesia can be accomplished either by intravenous or inhalational agents, with TIVA maintenance. This is advantageous when compared with the intermittent apnea technique, in that longer periods of uninterrupted surgical intervention can take place. Major drawbacks include lack of control over the airway and increased risks of surgical debris entering the distal airway.

Fire Prevention

One of the primary goals of airway management for laser airway surgery is the prevention of an airway fire. Each technique and device discussed thus far has its own inherent advantages and disadvantages with regard to preventing fire. In the proper hands and with the appropriate training and skills, virtually all airway fires can be avoided. Nonetheless, the only definite way to prevent fire is to avoid use of the laser altogether. As such, all anesthesiologists should be prepared to immediately manage an airway fire when providing an anesthetic for laser airway surgery. Upon recognition of a fire involving the endotracheal tube, all gas flows, including oxygen, should be immediately stopped and ventilation ceased. Simultaneously, any flames should be extinguished with saline and the endotracheal tube with deflated cuff should be removed from the airway. Mask ventilation of the patient's lungs should occur, followed by examination of the airway to assess for damage.

Additional steps can be taken to decrease the risk of fire. These include limiting the amount of oxidizing agents in the airway, using the lowest possible FiO_2 and the minimal laser power in density and duration that is feasible for the procedure, and covering the surrounding areas of the surgical field with saline-soaked towels, as seen in Fig. 47-8.[17,18]

Summary

There are numerous options for airway management during laser airway surgery. The correct choice is one that produces safe anesthesia for the patient, provides adequate

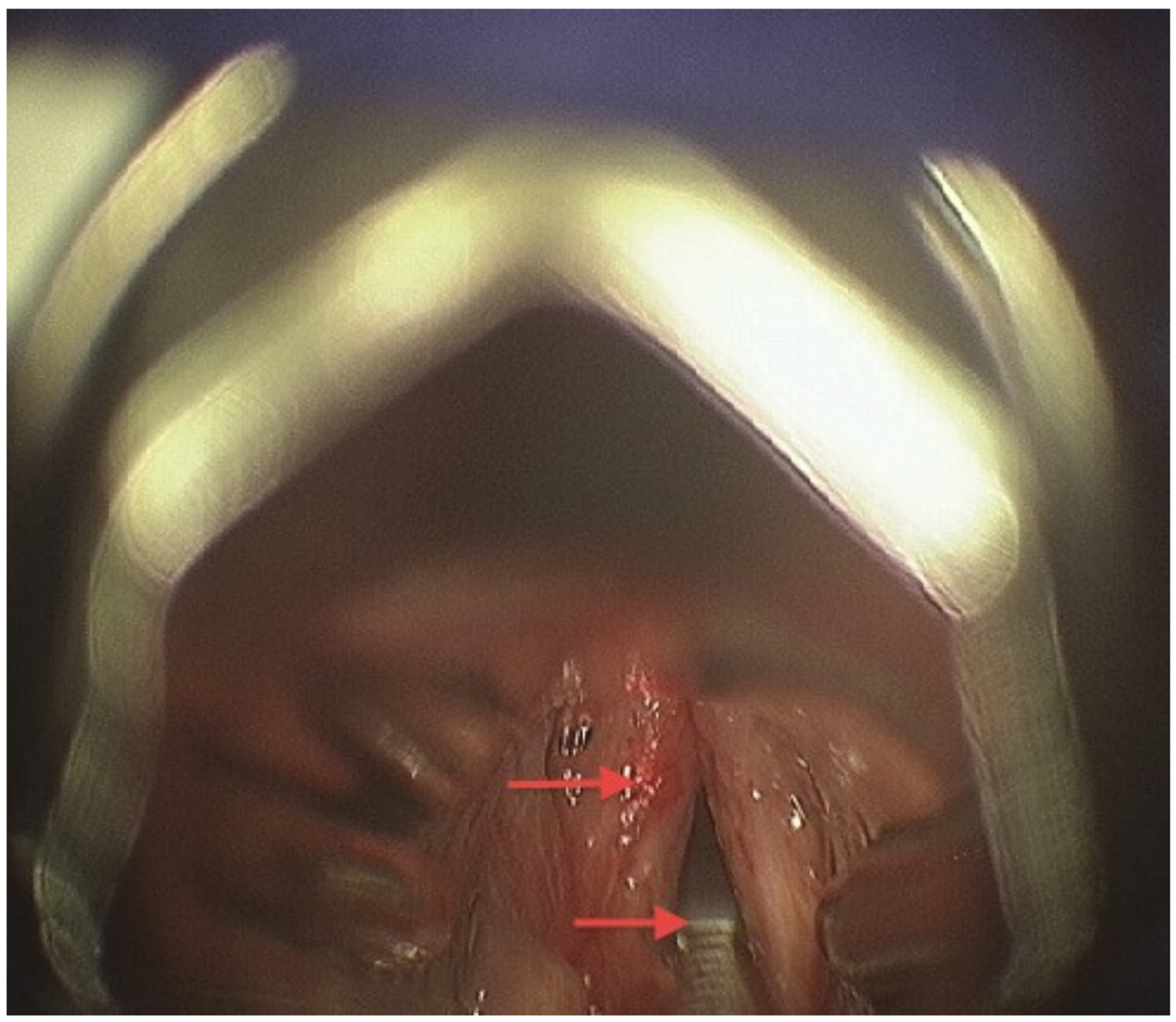


FIGURE 47-1 View of larynx with Mallinckrodt Laser-Flex endotracheal tube with double cuff seen just below vocal cords. Upper arrow indicates the lesion on the vocal cord. Lower arrow indicates the cuff of the endotracheal tube.

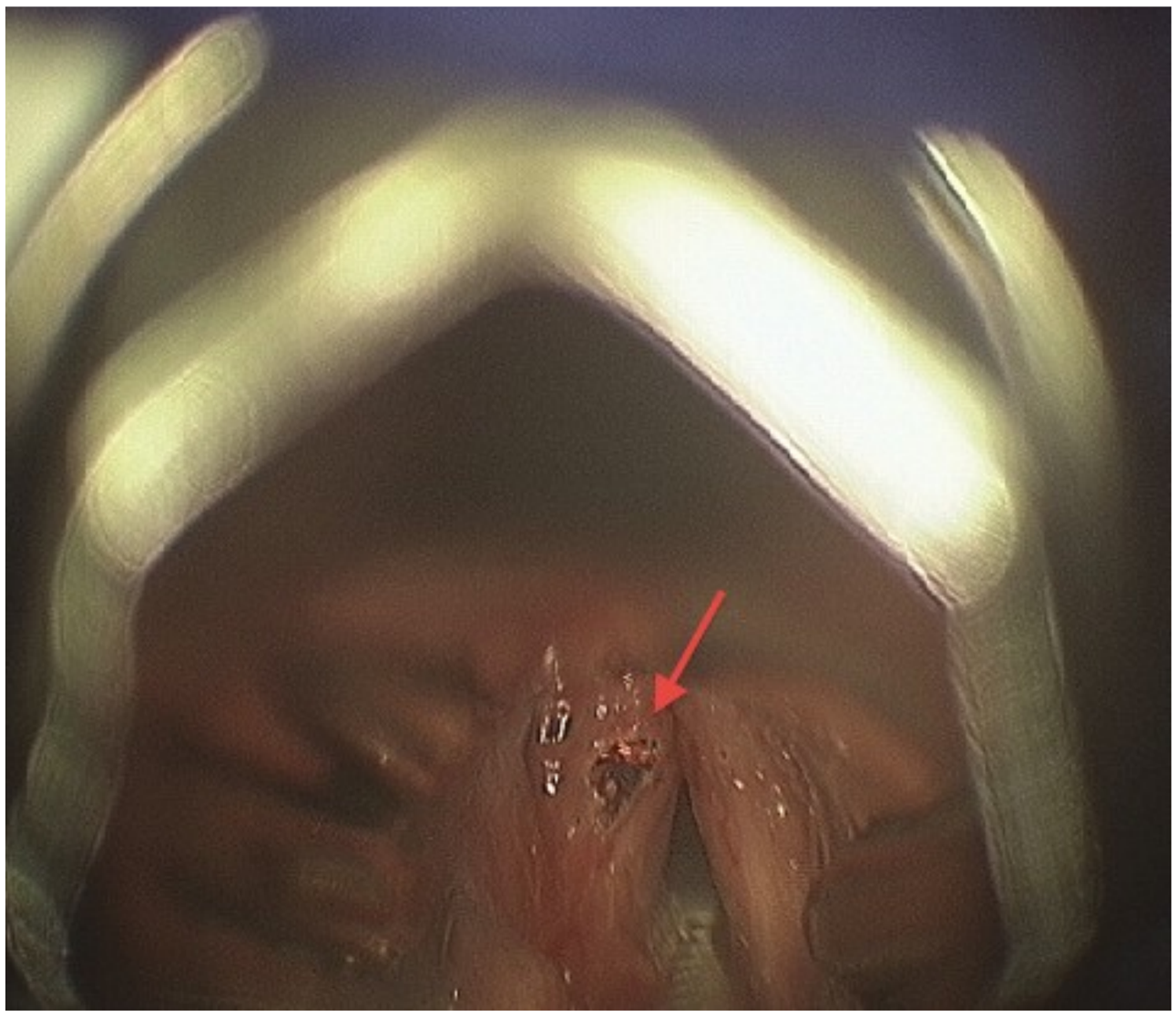


FIGURE 47-2 View of the larynx and vocal cord with CO_2 laser in use.



FIGURE 47-3 Mallinckrodt Laser-Flex endotracheal tube with double cuff.



FIGURE 47-4 Mallinckrodt Laser-Flex endotracheal tube, cuffless.

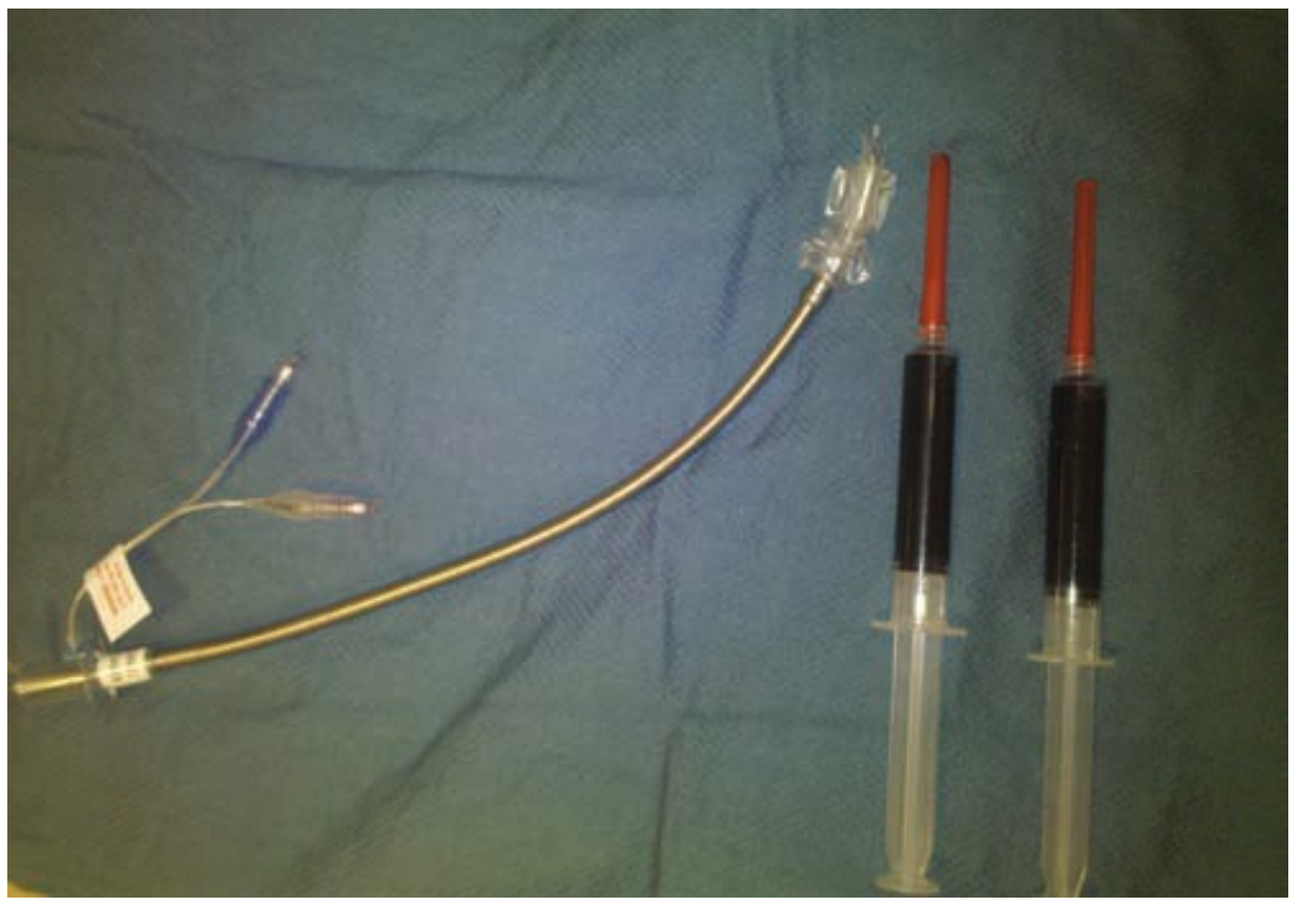


FIGURE 47-5 Mallinckrodt Laser-Flex double cuff tube with methylene blue.



FIGURE 47-6 Pilot cuffs of Mallinckrodt Laser-Flex tube filled with methylene blue.

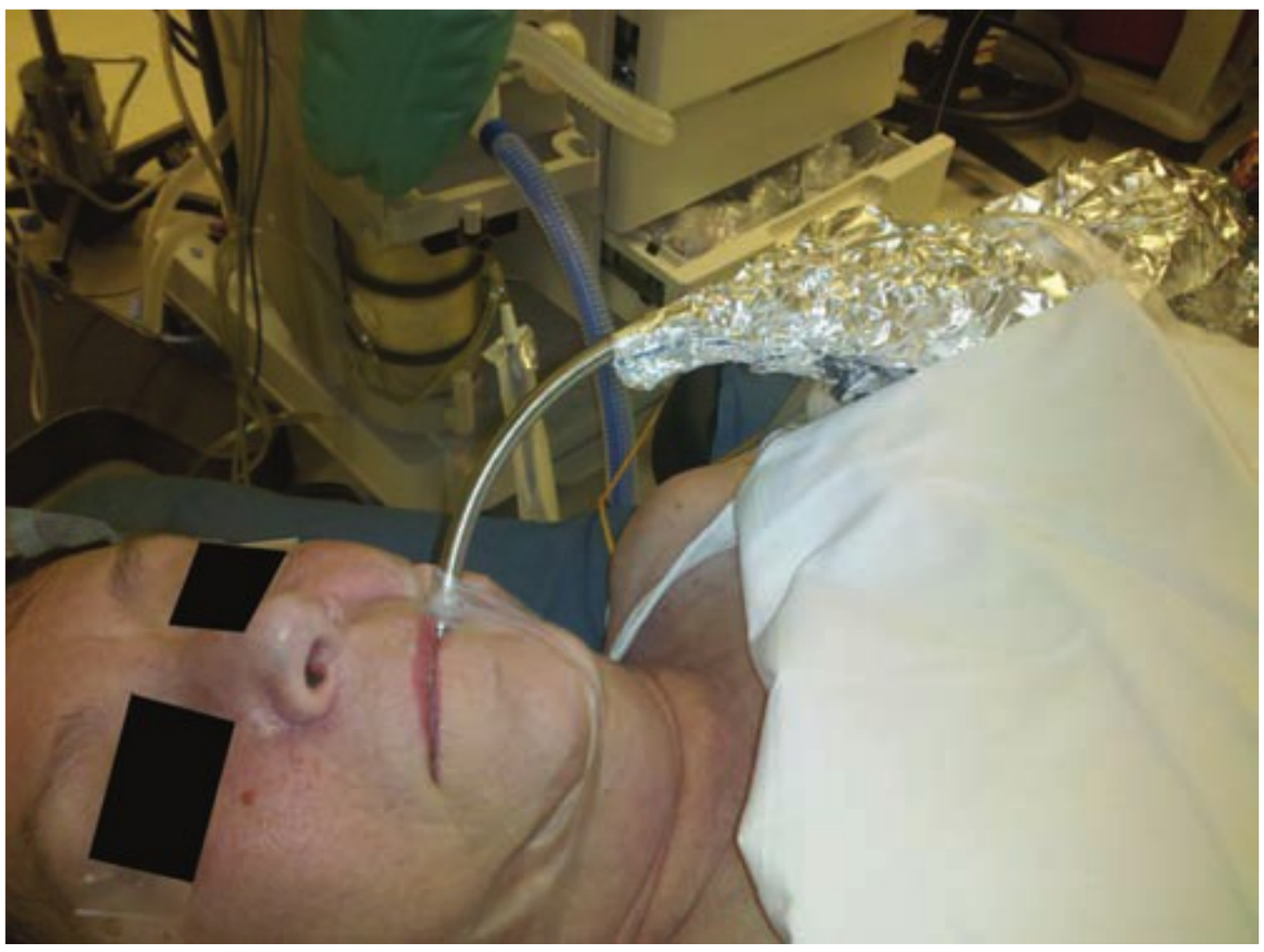


FIGURE 47-7 Mallinckrodt Laser-Flex tube with aluminum foil covering the PVC adapter and circuit.

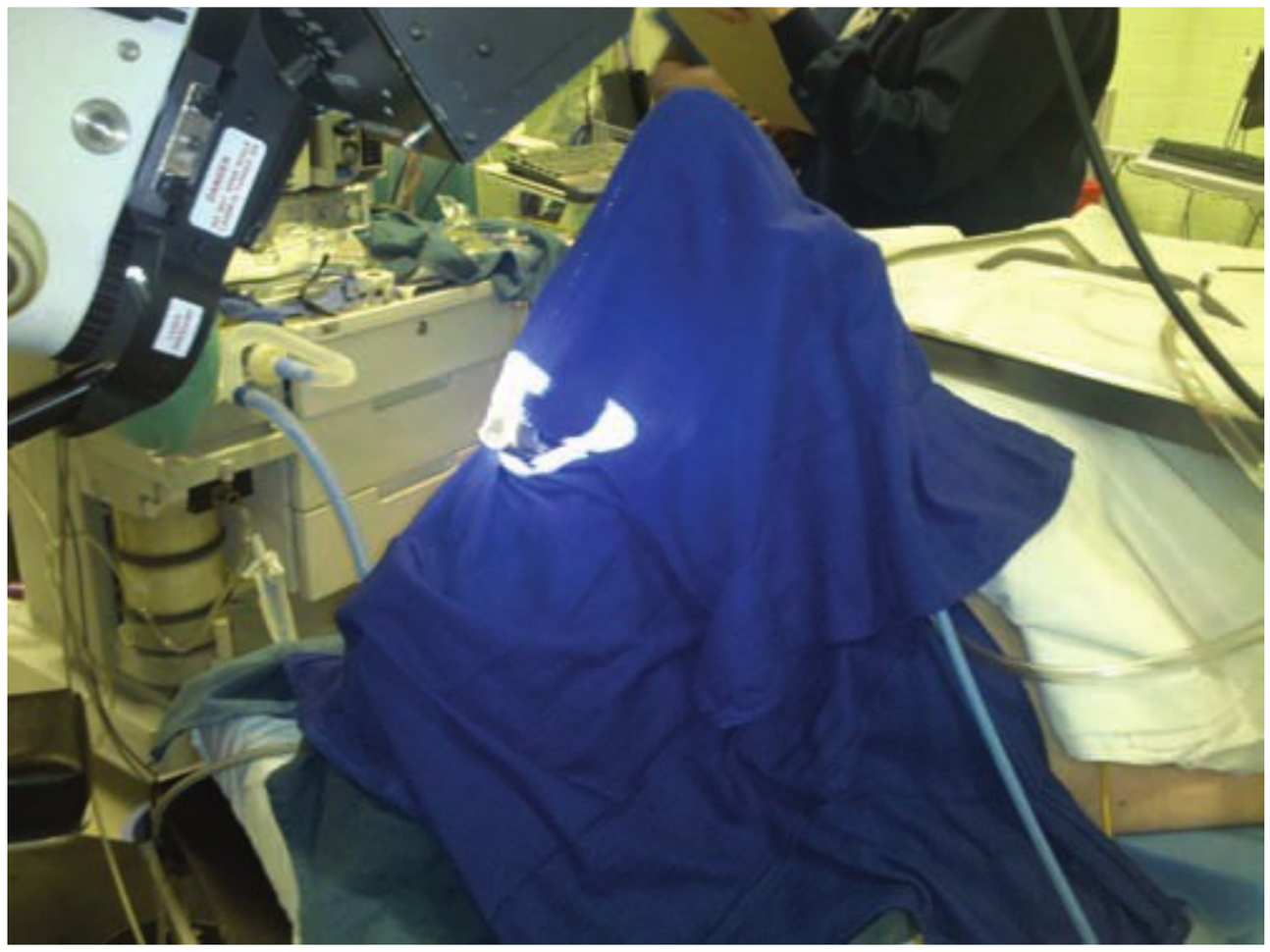


FIGURE 47-8 View of the operating field draped in saline-soaked towels.

operating conditions for the surgeon, and minimizes risk of fire from the laser. The anesthesiologist must be familiar with the techniques described above and be prepared to manage complications as soon as they appear.

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CHAPTER

48

High-Frequency Jet Ventilation

Miroslav Klain and Joseph Goode

WHAT IS HIGH-FREQUENCY JET VENTILATION?

There is often much confusion surrounding the non-specific term "jet ventilation" as it applies to what are really two different modalities, low-frequency jet ventilation (LFJV) and high-frequency jet ventilation (HFJV). Additionally, there are other modes of "high-frequency ventilation" (HFV), such as high-frequency oscillation (HFO) and high-frequency positive pressure ventilation (HFPPV) that are commonly confused with HFJV. As such, it is helpful to distinguish between these ventilatory modalities.

COMMON CHARACTERISTICS OF ALL MODES OF HFV

All types of HFV, including HFJV and HFO, are classified as forms of positive pressure ventilation. HFPPV is also a form of positive pressure ventilation, wherein a conventional style ventilator is operated at the upper end of its functional range. The introduction of both HFJV and HFO ventilators has supplanted the use of this modality.

The characteristics of all forms of HFV include rates greater than 60 per minute, which are commonly referenced in terms of "cycles per minute"(cpm) or Hertz (Hz) (eg, 60 cycles per minute or its equivalent, 1 Hz). Tidal volumes (V_T) are usually at or below anatomic dead space, and the peak airway pressures generated are lower than those of conventional positive pressure ventilation, resulting in decreased hemodynamic impairment.[1–8] Table 48-1 summarizes and contrasts the common characteristics of various modes of HFV with those of conventional mechanical ventilation.

We will focus in this chapter on LFJV and HFJV as these modalities are the most commonly used by the anesthesia provider in the perioperative period, the application of HFO being mostly confined to the realm of the adult and pediatric critical care setting.

COMMON CHARACTERISTICS AND OF LFJV AND HFJV

Jet ventilation, as the name implies, delivers a jet of fast streaming gas through a small diameter tubing and cannula to the patient's airway. Both types of jet ventilation require a high-pressure gas source, at a minimum wall source oxygen or oxygen via a compressed gas cylinder. Because the volumes are delivered through small diameter devices such as 14G catheters for rescue ventilation, the high pressure can be thought of as "work" or "potential energy" to overcome the resistance of these small diameters.[9] Jet ventilation does not require a cuffed endotracheal tube and is ideal where ventilation in "open" systems is required (eg, rigid bronchoscopy). In fact, jet ventilation is capable of drawing additional gas into the lungs in excess of what is delivered by the jet insufflation. This is formally described as a result of the jet injector effect, though much of the medical literature incorrectly attributes this to the Bernoulli or Venturi principles.[10,11] Many other devices such as gas nebulizers and oxygen facemasks leverage this effect and both LFJV and HFJV do as well. Both LFJV and HFJV depend on passive exhalation through the natural airways for elimination of CO_2, just as in conventional ventilation.

IMPORTANT DIFFERENCES AND ADVANTAGES OF HFJV OVER LFJV

Rate

LFJV is most commonly associated with a manually controlled insufflation device (hand jet insufflator) so that the provider depressing a demand or on–off valve controls the rate. (See also chapter 29). Practically speaking then, rates during the use of LFJV are generally in the conventional ventilation range. HFJV is of course delivered through a sophisticated mechanical ventilator, with electronically controlled solenoid valves controlling the flow of gas. Just as in conventional ventilation, the respiratory rate can be set at a various levels, though most high-frequency jet ventilators marketed in the United States have a maximum rate of 150 cpm.

Table 48-1

Comparison of Common Characteristics of HFV Modes and Conventional Ventilation

	HFJV	HFO	HFPPV	Conventional Positive Pressure Ventilation
Rate (Hz)[7,8,12,45]	1–10	2.5–40	1–2	<1
Tidal volume[7,8,45]	• At or approaching V_{DS} (2–4 mL/kg) • Changes passively as rate, inspiratory time, and driving pressure are changed	• <V_{DS} (1–3 mL/kg)	• >V_{DS} (2–5 mL/kg)	• >V_{DS} required (10 mL/kg)
Peak airway pressure[1–3,5–8, 17,45,46]	• <20 cm H_2O • Positive pressure maintained throughout the respiratory cycle	• Plateau pressure ideally <30 cm H_2O	• ≥20 cm H_2O • Plateau pressure ideally <30 cm H_2O	• ≥20 cm H_2O • Plateau pressure ideally <30 cm H_2O
Mean airway pressure[1–3,5–8,17,46]	• <10 cm H_2O	• Variable • 2–5 cm H_2O above that seen with conventional settings for the patient	• Ideally <10 cm H_2O	• Ideally <10 cm H_2O
Hemodynamic effects[47]	• Minimal	• Variable; setting dependent	• Variable; setting dependent	• Variable; setting dependent
Weaning and spontaneous ventilation[1,7,8,48]	• Superimposable over patient breaths	• No spontaneous ventilation; usually requires sedation and neuromuscular blockade	• Depends on ventilatory mode	• Depends on ventilatory mode

1 Hz is equal to 60 cycles (breaths) per minute.
Abbreviations: Hz, Hertz; VDS, dead space volume.

It should be noted that during HFJV, the adjustment of rate has the least impact on either oxygenation or ventilation because changes in rate do not directly affect minute ventilation (MV) as they do in conventional ventilation modes. MV is primarily determined by the set driving pressure and the inspiratory time.[12]

Inspiratory Time

In LFJV, the inspiratory to expiratory ratio of delivered ventilations is, as with the rate, manually controlled by the provider. This frequently results in a great deal of breath-to-breath variability. Modern high-frequency jet ventilators allow for a range of I:E ratios. Most jet ventilators express this in terms of the inspiratory time alone, with the expiratory time implied (eg, a setting of 30% would indicate 30% of the respiratory cycle as inspiration and 70% as expiration). As would be anticipated in conventional ventilation, increasing the duration of the inspiratory phase will result in greater delivery of gas and an increased MV. This is true of both LFJV and HFJV.

Driving Pressure

In both LFJV and HFJV, the phrase *driving pressure* is used to denote the pressure measured at the gas delivery valve before it opens to the patient. This becomes a simple expression for minute volume adjustments: the higher the driving pressure, the higher the delivered minute volume. This pressure can be expressed in pounds per square inch (psi) or in bar (1 bar is approximately equal to atmospheric pressure at sea level and equal to 14.5037 psi).

In HFJV (and ideally in LFJV) a reducing regulator allows for the adjustment of this pressure up or down. The maximal pressure that one is able to obtain depends on the compressed gas source, but for most central gas delivery systems in the United States this is approximately 50 psi. For most patients, optimal driving pressure settings will be between 20 and 30 psi, but pulmonary-related comorbidities could result in the need for either higher or lower settings. In HFJV, driving pressure is one of the key determinants of MV, oxygenation, and carbon dioxide elimination.[13,14]

Airway Pressures

Airway pressures in jet ventilation are determined by the amount of volume delivered to the lungs. The primary determinants of this are the set driving pressure and the inspiratory time. Increased driving pressure provides increased "energy" to overcome the resistance of the small diameter delivery tubing and, thus, increased volumes. An increased inspiratory time functions just as it does in conventional ventilation to deliver greater volumes. In general, peak airway pressures during HFJV are lower than those generated during conventional positive pressure ventilation, and this can be of great advantage across the range of applications for HFJV.[5,6,15–17] Because the lungs never fully exhale during HFJV, positive pressure is maintained throughout the respiratory cycle. As a result, although peak airway pressures are lower than conventional ventilation, mean airway pressures between the two modes are generally equivalent. Airway pressures in LFJV depends heavily on the operator manually controlling the rate and I:E ratio. Other significant contributing factors would include the cross-sectional area of the trachea and the ID and length of the delivery catheter. Animal studies have reported a range of pressures between 20 and 50 cm H20 using LFJV via transtracheal puncture with either a 14 g or 16 g catheter.

POTENTIAL COMPLICATIONS OF LFJV AND HFJV

Barotrauma

The most common complication of either type of jet ventilation is barotrauma, and the most common underlying etiology is unrecognized obstruction to outflow, either through the natural airways or in some circumstances through an endotracheal tube. This is counter to a common misconception that the high-pressure gas source itself is the cause of barotrauma. As discussed earlier, the high-pressure gas is essentially used as work to overcome the resistance of the small diameter ventilator delivery tubing and whatever jet device is attached to it. The pressures generated at the point of exit are significantly lower (consider that the hallmark of HFJV is *lower peak airway pressures* than in conventional ventilation) than the set driving pressure. A frequently used example is that with a set driving pressure of 20 psi, a standard length of delivery tubing, and incorporating a 14G catheter, one could expect to deliver between 500 and 600 mL with a 1 second inspiration.[18,19] Pressure in the lungs, then, depends on the volume delivered during each breath. The greater the volume delivered, the greater the pressure. A review of the literature reveals that the most common occurrence in cases of barotrauma is the development of an obstruction, often in the upper airway, which impedes egress.[20–26] If insufflation continues and this obstruction remains unrecognized, barotrauma ensues. This risk is higher in the setting of LFJV as the detection of impaired exhalation depends on the vigilance of the provider delivering the manual insufflations. HFJV offers the advantage of an integral alarm system designed to detect outflow obstruction. Modern high-frequency jet ventilators incorporate a sophisticated switching system that enables the delivery tubing itself to act as pressure tubing to a dedicated pressure transducer. At the end of the expiratory cycle, backpressure in the airway is measured, and if the set alarm limit is exceeded, delivery of additional breaths is stopped. This occurs at the end of each respiratory cycle, regardless of the set rate, providing breath-to-breath detection of potential outflow obstruction. The alarm level is adjustable but is often nondefeatable. A typical setting for this alarm limit is 20 cm H_2O.

Aspiration Protection in "Open Systems"

Frequently, jet ventilation of either type is used in the setting of "open" ventilatory systems (no cuffed endotracheal tube). Because of this, there is always the potential risk of aspiration. However, when using HFJV with a *minimum* rate setting of 60 cpm and a *minimum* inspiratory time of 30%, it has been shown that secretions will be pushed away from the glottic opening and to some extent expelled from the upper trachea (Fig. 48-1).[27] Although this is not to be construed as complete a protection as a cuffed endotracheal tube, smaller amounts of secretions and fluids can be kept out of the airway. This protection is not present during the use of LFJV, as typically LFJV is not occurring at the minimum required rate setting of 60 cpm. Other, less common, potential complications of these modes of ventilation are summarized in Table 48-2.

GUIDELINES FOR THE USE OF HAND JET INSUFFLATORS

As noted earlier, unrecognized obstruction to outflow is almost always a contributing factor in barotrauma during all forms of jet ventilation; however, there is a predominance of cases associated with LFJV in the literature. This is in large part due to the lack of the previously described end expiratory monitoring system that exists in

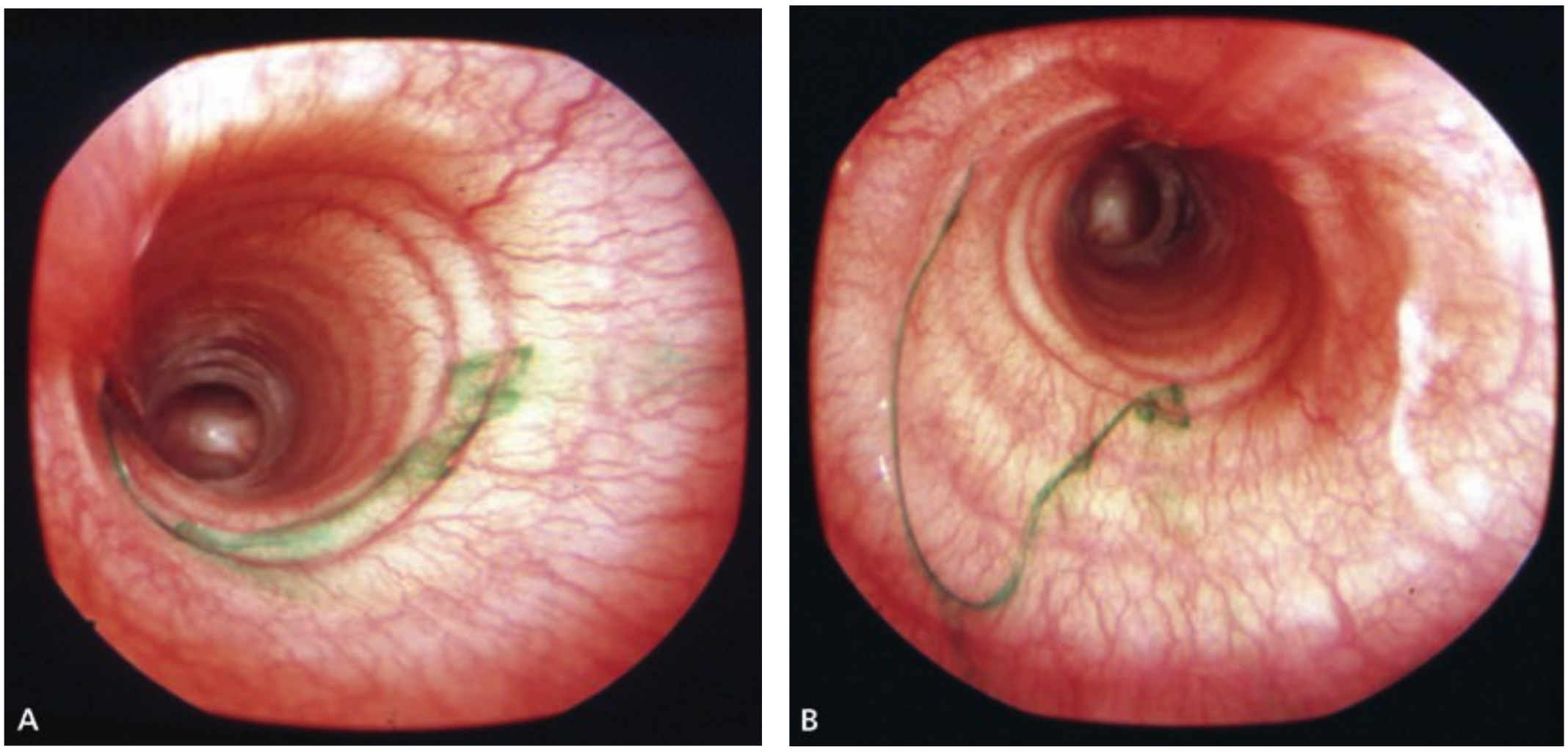


FIGURE 48-1 Movement of secretions from the trachea toward the glottic opening during HFJV. **A:** the dye-colored secretions are more distal in the trachea and have been pushed closer to the glottic opening **(B)**.

Table 48-2

Summary of Potential Complications and Disadvantages of the Use of LFJV and HFJV

	LFJV	HFJV
Tension pneumothorax	√	√
Tension pneumomediastinum	√	√
Subcutaneous air (misplaced transtracheal jet catheter)	√	√
Aspiration (in open systems)	√	Only if rate is <60 and inspiratory time <30%
Lacks end expiratory pressure monitoring	√	Available
Hypothermia	√	√
Lacks humidification system	√	Available

all modern high-frequency jet ventilators. Because of this the authors, though recognizing the important role transtracheal jet ventilation plays in rescue maneuvers as per the American Society of Anesthesiologists (ASA) Difficult Airway Algorithm, strongly discourage the elective use of hand jet insufflators by practitioners with little or no experience with jet ventilation. The following are some suggested guidelines in regard to the application of LFJV via hand jet insufflators.[24]

Device Specification

There are four primary components that should be present on any hand jet insufflation device: (1) a connection to a high-pressure gas source, (2) a reducing regulator, (3) an on/off (demand) valve, and (4) a pressure gauge.

Depending on the setting, these devices can be connected to wall source oxygen or to an oxygen cylinder. In either case, a reducing regulator is essential to decrease the pressure from the usual 50-psi wall source pressure (or the potentially even

higher cylinder pressure). There is also a button or lever that is manually depressed to open a valve and allow the flow of gas to commence. What is often overlooked is the pressure regulator, which displays the pressure setting at the valve before it is opened. Every hand jet insufflation device should have one. Most do, but it is critical that the gauge be proximal to the on/off valve. Many commercial preparations of these devices are sold with the gauge distal to the on/off valve, so that the set driving pressure is never known (Fig. 48-2). Any pressure reading that registers during the open phase is of little value clinically, and these gauges are incapable of measuring backpressure during exhalation as they are calibrated to measure psi and not cm H_2O.

Ventilation Guidelines

Multiple studies have characterized the flow delivery profiles of transtracheal jet ventilation catheters. Yealy et al[18,19] demonstrated that at a set pressure of 25 psi with a 14G catheter, up to 1,000 mL/second could possibly be delivered; at a pressure of 50 psi this can be upwards of 1,700 mL/second. Given this, it is clear that insufflation times of 1 or even half a second can produce more than adequate V_T for both oxygenation and ventilation. Delivered volumes and airway pressures increase linearly with increases in driving pressure and/or inspiratory time, potentially increasing the risk of barotrauma. We recommend that insufflation should be no longer than 1 second, with a minimum inspiratory to expiratory ratio (I:E) of 1:2, if not 1:3, especially as obstruction to outflow is a primary etiology for barotrauma. We further recommend that when hand jet insufflation is necessary, a single provider should be dedicated to this task alone. During an emergency airway scenario, the dynamics of airway inflow and outflow can show considerable fluctuation; it is unlikely that a single provider can safely manage this and other hemodynamic or anesthetic needs. If longer periods of transtracheal jet ventilation are required, transition to HFJV is a good choice if available.[24]

Myths of LFJV

A common misconception is that by attaching a resuscitation bag to the transtracheal catheter (multiple methods have been published, most commonly by placing a 15 mm endotracheal tube adaptor into a 3 cc syringe, which is then connected to the catheter) one may be able to adequately ventilate the patient. This myth persists despite multiple studies demonstrating the ineffectiveness of this approach; Yealy et al demonstrated maximal V_T through a 14G catheter of 235 mL with this type of system.[28]

Another misconception is the reliability of devising a connection from the common gas outlet of the anesthesia machine to the placed transtracheal catheter. The ability to achieve adequate V_T by this method is entirely machine specific and depends on the positions of the low-pressure relief and check valves. As described by Olympio,[29] if the check valve is positioned proximally to the relief valve, then it is not possible to generate adequate driving pressure for transtracheal ventilation. Therefore, one must know the specifics of each individual anesthesia gas machine (AGM), as some larger institutions use multiple models and manufacturers, which can be problematic. Additionally, some newer AGMs have no common gas outlet at all.

GUIDELINES FOR THE USE OF HFJV

The Role of Rate, Inspiratory Time, and Driving Pressure in Gas Exchange

Much as in conventional ventilation, a primary factor in both oxygenation and CO_2 elimination is minute volume. As mentioned above, rate has little effect on either

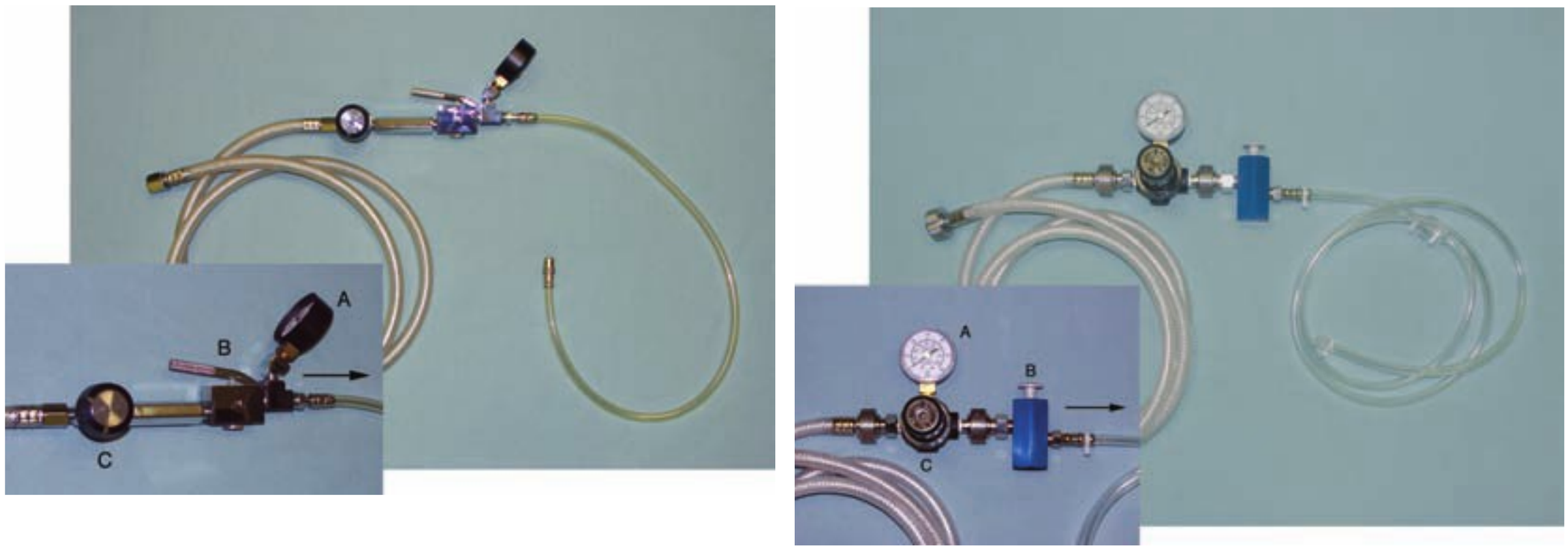


FIGURE 48-2 Two examples of Hand Jet Insufflators: incorrect (left) and correct (right) placement of the pressure gauge. A = pressure gauge; B = 'on-off' or demand valve; C = pressure reducing regulator.

oxygenation or carbon dioxide elimination, especially in the commonly used range of 100 and 200 cpm. In general, the higher the respiratory rate, the greater the minute volume that will be needed to achieve a similar $PaCO_2$ level. When rates exceed 400 cpm, CO_2 elimination begins to be further impaired.[12] Most high-frequency jet ventilators display both V_T and minute volume, but there is no direct way to adjust V_T as with conventional ventilators. V_T changes passively as rate, driving pressure, and inspiratory time are changed (individually or in combination). Minute volume (and thus V_T) linearly increases as driving pressure is increased. Minute volume is also increased, as would be expected, when inspiratory time is increased. The MV required for normal adequate oxygenation and eucapnia is generally higher than in conventional ventilation, usually twice as large.[30]

Initial Settings

Generally accepted starting ventilatory settings for HFJV are a rate of 100 cpm and an inspiratory time of 30%. It is recommended that the initial driving pressure setting be low (in the event that there is unrecognized outflow obstruction) and rapidly increased while observing chest excursion and data from standard monitors, especially pulse oximetry. A good starting setting for the integral end expiratory pressure alarm is 20 cm H_2O.

Monitoring the Adequacy of Ventilation

Capnography is unreliable in the setting of HFJV. At best, a depressed waveform will be displayed, if any at all. As HFJV results in some degree of constant pressure in the lungs, full passive exhalation as in conventional ventilation is never achieved. In fact, there is some constant egress of gas, even during the inspiratory phase. Because of this, a true end tidal CO_2 value is never obtained. The gold standard for assessment of adequacy of oxygenation and ventilation is an arterial blood gas. If ventilation is being delivered through a cuffed endotracheal tube using one of the commercially available jet ventilation adaptors (eg, the Acutronic Swivel Connector with 15 mm Jet Catheter: Acutronic Medical Systems AG, Hirzel (Zurich), Switzerland), one can intermittently stop HFJV, deliver a standard tidal breath using the anesthesia circuit/reservoir bag, and observe the measurement on a capnograph. It is best to catch the first tidal breath on the monitor as subsequent CO_2 measurements will begin to reflect the result of manual ventilation (Fig. 48-3).

Anesthetic Management

As the vaporizers used for delivery of modern inhaled anesthetics are not designed for use with high-pressure gas sources, it is not yet technically feasible to safely use inhaled anesthetics with HFJV. Depending on the model of jet ventilator available, it may be possible to use an admixture of nitrous oxide, which comes as a compressed gas. But because it is difficult to scavenge the expired gas when a closed system is not used, its use is not recommended. The most common method of managing the anesthetic during HFJV is to use a total intravenous anesthetic technique appropriate to each individual patient.

Humidification

Because large volumes of cold, compressed gases are delivered to the patient during HFJV, it is necessary to deliver humidification for procedures that will last longer than 60 minutes to avoid drying of the airway mucosa. All of the high-frequency jet ventilators sold in the United States have the option of an integral heated humidification

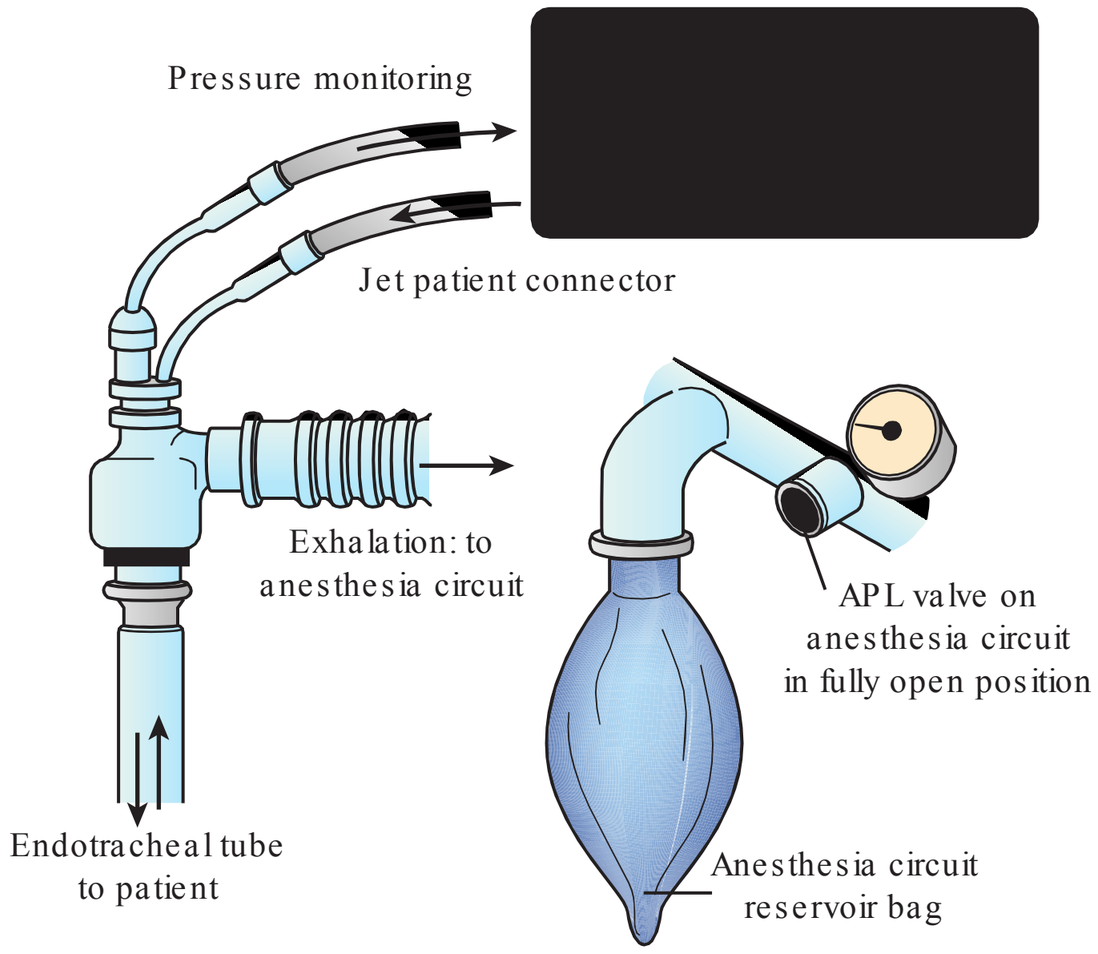


FIGURE 48-3 Diagrammatic representation of a typical connection to the anesthesia circuit during the use of HFJV.

system. It is also possible to administer humidification by attaching a y-connector at the tip of the jet delivery tubing; an infusion of normal saline can then be administered into the jet stream, allowing it to be nebulized.

PERIOPERATIVE APPLICATIONS OF HFJV

Most practitioners are only acquainted with the role of jet ventilation in the management of the difficult airway as per the ASA Difficult Airway Algorithm. However, HFJV has been used in various circumstances in the perioperative setting (Table 48-3), and there are newly emerging settings for its application. Although not exhaustive, we briefly highlight some of the potential applications for HFJV below.

Elective Transtracheal Jet Ventilation for Assistance with Fiberoptic Bronchoscopy

In the setting of a recognized difficult airway, the ASA Difficult Airway Algorithm lists awake fiberoptic intubation as an option that should be seriously considered. It is possible to use HFJV in this situation via percutaneous placement of a 14G catheter across the cricothyroid membrane, after the usual application of topical local anesthetics for awake fiberoptic intubation. There are several potential advantages to this technique. First, it allows for confirmation of the ability to ventilate the patient. This is especially valuable in the setting of limited mouth opening or maxillofacial injury and in the presence of cervical spine injuries where hyperextension of the neck is of concern. Second, it provides for direct intratracheal administration of oxygen. Third, it is well tolerated by patients at the low driving pressures recommended (≤15 psi). Fourth, the jet can be used to nebulize local anesthetic agents in the trachea, helping to block the sensory pathways of the recurrent laryngeal nerve. Fifth, the continuous egress of gases during HFJV can both provide some degree of protection from aspiration and partially stent open the glottis to facilitate endotracheal tube placement.[6,31,32]

Table 48-3

Number of Cases Accumulated in Various Perioperative Settings

Unpublished data from accumulated cases at Montefiore University Hospital through from 1982 through 1996

Location for HFJV	
Operating room	1987
Postanesthetic care unit	63
ICU	279
Transport	120
Lithotripter	83
Other	64

ENT Procedures

Management of cases that involve examination and/or manipulation within the larynx requires that both the surgeon and the anesthesia team must share the same space. Although oftentimes a very small 5.0 mm Internal Diameter (ID) endotracheal tube will be adequate in terms of visualization for the surgeon, there are instances when even these are too large. The smaller catheters and specialized endotracheal tubes that are used with HFJV or LFJV eliminate competition for the airway with the surgeon and provide reliable, continuous ventilation in the setting of an "open" system. A 14 French insufflation catheter is usually adequate for adults (10 F for children). There are specialized tubes, such as the Hunsaker Mon-Jet Ventilation Tube: Medtronic, Minneapolis, MN, which have been designed for use during microlaryngeal laser surgery.[33]

Rigid Bronchoscopy

During rigid bronchoscopy, HFJV provides all of the expected advantages in the setting of an open ventilatory system (see chapter 43). The ability to provide uninterrupted ventilation provides for greater hemodynamic stability for the patient. There are two primary methods to establish HFJV in this setting. Most rigid bronchoscopes have a side arm that either has an integral attachment point for the jet delivery tubing or accepts an appropriate adaptor. A second approach is to nasotracheally insert a 14 F insufflation catheter under direct vision. The bronchoscope itself is the conduit for exhalation in either setting. The advantage of the insufflation catheter is that it may be left in place, maintaining ventilation, during periods when the rigid bronchoscope is removed. Additionally, the insufflation catheter may be left in place at the end of the procedure to provide respiratory support during weaning and emergence from the anesthetic.[4,34,35]

Major Airway Reconstructive Procedures

The ability to deliver ventilation through small diameter insufflation catheters can provide some unique advantages for the anesthetic and surgical management of reconstructive procedures on the tracheobronchial tree. In some settings, such as complete carinal reconstruction, the application of HFJV is the only viable alternative to cardiopulmonary bypass, providing uninterrupted ventilation through low-profile devices, which do not impede access to the entire circumference of the trachea and mainstem bronchi, essential for achieving good anastamosis.[36–39]

Alternative to Continuous Positive Airway Pressure in One-Lung Ventilation

Ventilation/perfusion mismatching can result in periods of hypoxia during one-lung ventilation for thoracic procedures. Standard interventional maneuvers are the institution of continuous positive airway pressure (CPAP) at 5–10 cm H_2O or the application of positive end expiratory pressure (PEEP) to the ventilated lung. An alternative approach is to apply low driving pressure HFJV to the operative lung. Wilks et al[40] reported minimal lung distention and improved oxygenation with the use of HFJV at a driving pressure of 15 psi (Fig. 48-4).

Extracorporeal Shock Wave Lithotripsy

Cormack et al compared two anesthetic management strategies for Extracorporeal Shock Wave Lithotripsy (ESWL) performed under general anesthesia: spontaneous ventilation versus HFJV. The smaller V_T delivered during HFJV created less movement of the diaphragm and the kidney with each breath, resulting in less excursion of the targeted kidney stone out of the shock focus. They noted significantly fewer shocks for effective stone ablation (median 2000 for HFJV vs median 3000 for spontaneous ventilation) with no difference in postoperative recovery time.[41] These authors speculate that as fewer shocks are needed when using HFJV, this could result in a decrease in the incidence of postoperative pain and nausea associated with ESWL when performed under general anesthesia with spontaneous ventilation.

Radiofrequency Ablation of Atrial Fibrillation

The use of percutaneous radiofrequency catheter ablation as an alternative to the surgical MAZE procedure for the treatment of chronic paroxysmal atrial fibrillation has become widespread. The procedure necessitates an atrial septal puncture to access the posterior left atrium. Many centers perform this procedure under heavy sedation, but Goode et al[42] were able to demonstrate significantly reduced procedure times by using general anesthesia and HFJV. HFJV creates an essentially quiet cardiac field for the procedure, primarily by reducing the variation in left atrial volume seen in both spontaneous and conventional mechanical ventilation. Fewer ablations were needed as this more stable posterior left atrial environment resulted in decreased incidence of ablation catheter dislodgement.

Oxygen Insufflation in Sedation Cases

Drawing on previously reported clinical experience using elective TTJV for awake fiberoptic bronchoscopy, Chernus presented an intriguing series of cases in which 20 patients scheduled for esophagogastroduodenoscopy (EGD) who had an SpO_2 of < 90% on nasal cannula received HFJV via a nasotracheally placed 11 F tube exchange catheter. All patients remained spontaneously breathing over top of the jet flow (set between 0.5 and 1.2 bar). All maintained SpO_2 greater than 97%, tolerated the modality well and had no resultant complications.[43]

Flexible Bronchoscopy and Endotracheal Tube Exchange

With the introduction of specific adaptors for use during fiberoptic bronchoscopic procedures in intubated patients, providers often forget that significant decreases in arterial oxygenation can occur. This is a result of either a loss of delivered volume when the fiberoptic scope is introduced through the diaphragm of the bronchoscopy adaptor, or a leak of delivered volume if the diaphragm does not tightly seal against the bronchoscope. Guntupalli et al demonstrated that tracheobronchial suctioning can significantly decrease PaO_2 up to 90 torr, but using HFJV during these procedures resulted in a decrease of PaO_2 of only 15 torr.[44] This difference is seen because of the uninterrupted nature of the ventilation provided by HFJV in this setting. This difference may be critical in patients exhibiting symptoms of respiratory failure. For the same reasons, HFJV should be the preferred mode of ventilation during endotracheal tube exchange. Most commercial airway exchange catheters have a hollow lumen and provide adaptors for connection to either a hand jet insufflator or a high-frequency jet ventilator. There have been cases of barotrauma in attempts to ventilate during endotracheal tube exchange.[21,24] Benumof has identified one source of the error: using a catheter with too large a diameter with the result that annular space in the endotracheal tube around the exchange catheter is insufficient for exhalation (obstruction to outflow).[21] HFJV offers clear advantages in this setting: uninterrupted ventilation providing better cardiopulmonary support and hemodynamic stability for the patient as well as early detection of any obstruction to egress via the built in end-expiratory alarm system.

Aside from these specific indications, we believe that HFJV should be used in situations where its characteristics offer an advantage during ventilatory support. These include emergency transtracheal ventilation (because of a lower incidence of barotrauma), airway leaks and bronchopulmonary fistula (because of the ability to ventilate even in the presence of airway leaks), any open system where it would be deleterious for the patient to have ventilation interrupted, and procedures requiring a quiet operating field as the respiratory-related motion of the heart, lungs, and abdominal organs is considerably less than in conventional ventilation.

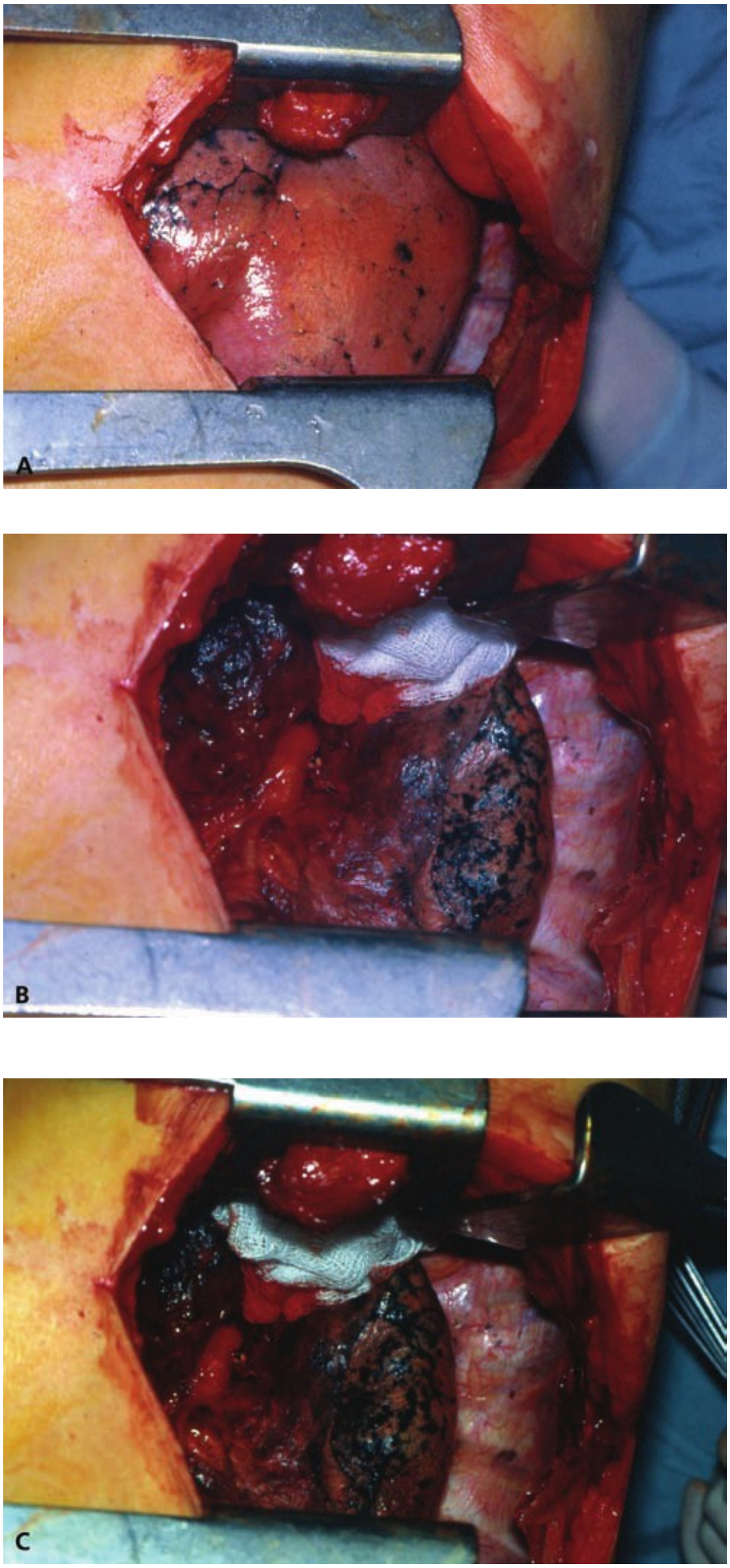


FIGURE 48-4 The use of HFJV in place of CPAP in one-lung ventilation. **A:** the fully inflated lung in an open thoracotomy. **B:** the same lung collapsed after lung isolation using a double lumen endobronchial tube. **C:** the lung with low driving pressure HFJV applied.

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PART XIV

Unique Facets of Airway Management by Discipline

CHAPTER 49

Airway Management in Critical Care Medicine

James M. Dargin and Lillian L. Emlet

INTRODUCTION

Airway management in critically ill patients, who have exhausted their physiologic reserve and are under undue stress, can have disastrous consequences. Further complicating matters, the critically ill often require airway management in settings outside of the intensive care unit (ICU) where experienced providers and appropriate equipment and medications may not be readily available. Hypoxia, hemodynamic instability, elevated intracranial pressure, emesis, gastrointestinal bleeding, and postextubation laryngeal edema are common conditions that make airway management challenging in the critically ill. Not surprisingly, complications during airway management account for a significant percentage of adverse events in the ICU.[1–3] The medical complexity of patients in the ICU is an important contributing factor to airway-related complications. Therefore, an understanding of the individual patient's physiologic derangements can help formulate an airway management plan to avoid adverse events.

SETTING

Although the majority of critically ill patients undergo tracheal intubation in the ICU setting, airway management may also occur in the inpatient wards or elsewhere in the hospital, such as the radiology suite or special procedures laboratories. In the ICU, equipment such as infusion pumps, dialysis machines and mechanical ventilators limit access to the patient. Air mattresses used to prevent pressure sores in ICU patients can make proper positioning difficult as well. Outside of the ICU, airway equipment, appropriate medications, and experienced personnel may not be readily available. Medical emergency teams staffed by expert personnel who are appropriately equipped and available 24 hours per day may help to overcome such challenges.[4]

PERSONNEL AND EQUIPMENT

Emergency tracheal intubation outside of the operating room (OR) is associated with a decreased complication rate when performed in the presence of an attending physician, rather than by unsupervised trainees.[1,5] Complications during airway management in the critically ill also can be minimized by having the proper equipment and medications necessary to manage the difficult airway. Unfortunately, only 50% of ICUs in the United States have a difficult airway cart and fewer than 5% have the equipment suggested in the American Society of Anesthesiology Practice Guidelines.[6,7] At the University of Pittsburgh Medical Center, we have standardized the approach to airway management in the critically ill by creating a portable airway bag that contains the medications and equipment necessary to manage both routine and difficult airways (Table 49-1).[8] The contents of the airway bag are uniform, such that any desired piece of equipment can be quickly located (Fig. 49-1). The standardized airway bag is stored in each ICU, is brought to all medical emergency calls within the hospital, and is restocked by the hospital central supply department after each use.

AIRWAY ASSESSMENT

Predicting the difficult airway allows for preparation of the proper equipment and resources to ensure successful intubation on the first attempt. Unfortunately, many of the traditionally described predictors of difficult intubation have not been validated in the critically ill.[9] In fact, Mallampati classification, thyromental distance, and neck mobility cannot be assessed in many patients undergoing emergency intubation due to lack of patient cooperation, altered mental status, or cervical spine immobilization.[10] However, several conditions commonly encountered in the critically ill will likely cause difficulties during airway

Table 49-1

Medical Emergency Team Airway Bag Contents

Routine Airway Equipment	Difficult Airway Equipment
Tongue blade	Intubating stylet (bougie)
Laryngoscope handle with batteries	Airtraq optical laryngoscope
Magill forceps	Laryngeal mask airway
Gloves	Jet ventilation equipment
No. 3, no. 4 Miller blades	Cricothyrotomy equipment
No. 3, no. 4 Macintosh blades	Availability of fiberoptic bronchoscope on request
No. 6, no. 7, no. 7.5, no. 8 endotracheal tubes	Availability of video laryngoscope (Glidescope)® on request
Endotracheal tube stylets	
Disposable colorimetric CO_2 detector	
Oral airways	
Nasal airways	
Medications	
Etomidate	
Propofol	
Benzocaine spray	
Succinylcholine	
Rocuronium	
10cc syringe	

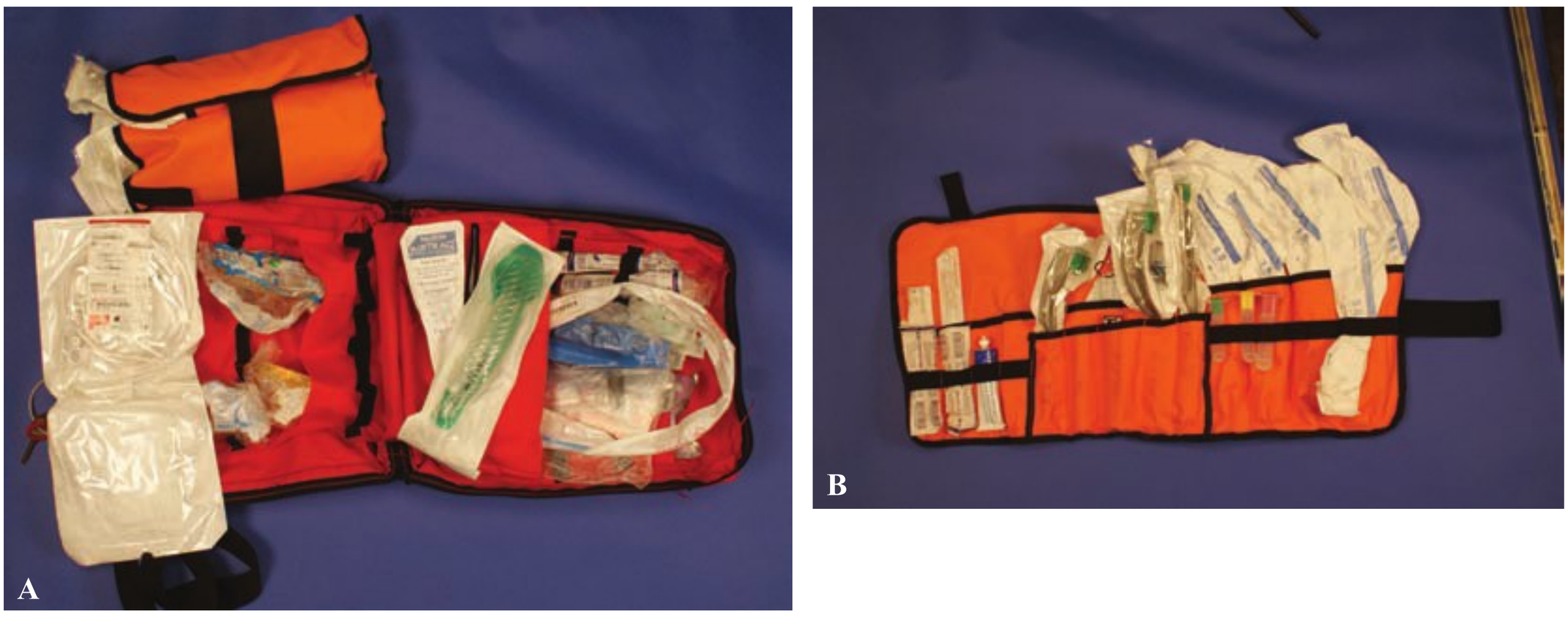


FIGURE 49-1 **A:** the airway bag used in the ICUs and during medical emergency calls at the University of Pittsburgh Medical Center. **B:** the contents of the airway bag used in the ICUs and during medical emergency calls at the University of Pittsburgh Medical Center.

management. Upper airway obstruction from a hematoma, abscess, angioedema, epiglottitis, or postextubation laryngeal edema can hinder mask ventilation, intubation, and the use of an extraglottic rescue device. The presence of blood, secretions, or vomitus in the airway can obscure laryngoscopic view. In addition, increased resistance from reactive airways; poor lung compliance in patients with significant airspace disease; and reduced thoracoabdominal compliance from ascites, abdominal compartment syndrome, or flail chest can make the use of mask ventilation or extraglottic rescue devices difficult. Thus, a patient who would be predicted to have a routine airway for elective

intubation can pose a challenge when critically ill, and it would be wise to over-prepare, rather than under-prepare during airway management in the critically ill.

PREOXYGENATION

Increased oxygen consumption, ventilation-perfusion mismatching, decreased cardiac output, and decreased hemoglobin concentration all reduce the time to hemoglobin desaturation in critical illness.[11] In patients with cardiopulmonary compromise, the traditional technique of preoxygenation may not result in large increases in oxygen saturation, and prolonged periods of attempted preoxygenation may even worsen oxygenation in the critically ill.[12] Thus, the goal of preoxygenation in the critically ill should be to improve the O_2 saturation to the mid to high 90% range, and tracheal intubation should not be delayed while trying to further preoxygenate a patient who has an acceptable O_2 saturation. In cases of hypoxia refractory to high-flow oxygen, assisting the patient with positive pressure breaths delivered with a bag-valve-mask or with noninvasive positive pressure ventilation may be helpful in achieving an O_2 saturation greater than 90%.[13] The supine position tends to cause atelectasis of the well-perfused lung bases, causing worsening hypoxia. Therefore, preoxygenation can be further optimized by leaving the patient in the upright position until just before unconsciousness is induced.[14] Consideration for nasal cannula apneic oxygenation for obese patients may be helpful to extend the time prior to desaturation during direct laryngoscopy, and, theoretically, it is an inexpensive method that could be used for all critically ill patients.[15]

PHARMACOLOGY

Laryngoscopy and tracheal intubation can cause a number of physiologic responses that can be particularly harmful in the critically ill, including hypertension, tachycardia, and increased intracranial pressure. The ideal induction agent would rapidly cause unconsciousness and amnesia, prevent the adverse physiologic responses to intubation, maintain stable hemodynamics and cerebral perfusion, and provide excellent conditions for laryngoscopy. Unfortunately, none of the available agents meet all of these criteria, and the anticipated response to tracheal intubation, as well an understanding of the side-effect profile of different induction agents, will dictate which medications are to be used.

Etomidate has rapid onset of action, no direct effects on vasomotor tone, does not cause an elevation in intracranial pressure, and generally provides excellent intubation conditions, which explains its widespread use in the critically ill. Etomidate causes sympatholysis and hypotension in patients who require a high sympathetic drive to maintain their blood pressure, and a reduction in dose from the standard 0.3 to 0.2 mg per kg may mitigate this effect. Etomidate causes a reversible, dose-dependent decrease in cortisol production and should be used with awareness of this side effect in patients with sepsis, who have a high incidence of critical illness-related adrenal insufficiency. Ketamine appears to be an acceptable alternative to etomidate in septic patients.[16] Ketamine causes a sympathomimetic response that can lead to an increase in heart rate and blood pressure, which may be detrimental in some cases (eg, aortic dissection) and desirable in others (eg, shock states).[17] Ketamine also possesses bronchodilator properties and may be useful in asthma or chronic obstructive pulmonary disease. However, ketamine may cause an increase in intracranial pressure, and its use in patients with intracranial pathology is controversial. Propofol decreases intracranial pressure and cerebral oxygen demand, may have some antiepileptic properties, and has a rapid onset and a short half-life. However, propofol causes vasodilation and can result in hypotension, particularly in hypovolemic patients and the elderly.[17] Propofol may be considered for hemodynamically stable patients with status epilepticus or intracranial hypertension. Midazolam has a relatively slow entry into the central nervous system (up to 10 minutes) when compared with etomidate and ketamine (2 to 3 minutes) and may cause hypotension in the critically ill, making this drug a less desirable induction agent.[17,18]

Succinylcholine is the most commonly used agent for neuromuscular blockade during rapid sequence intubation (RSI), owing to its rapid onset of action and its relatively short duration of action. In patients with known hyperkalemia or in conditions where the acetylcholine receptor is upregulated, such as spinal cord injuries, stroke, neuromuscular disorders, myopathies, and burns, a life-threatening increase in the serum potassium level may occur after the administration of succinylcholine. Rocuronium does not cause a significant hyperkalemic response and when given at a dose of 1 mg per kg, has a rapid onset of action and provides acceptable intubating conditions but a prolonged recovery (45 to 60 minutes).[19]

APPROACH TO THE AIRWAY

In patients who are completely unconscious, intubation often can be attempted without the use of induction agents or neuromuscular blockers. Otherwise, a more deliberate plan should be developed as time permits (Fig. 49-2). The importance of first pass intubation success cannot be overemphasized: more than two attempts at intubation has been associated with an increased risk of major complications in the critically ill.[20] Furthermore,

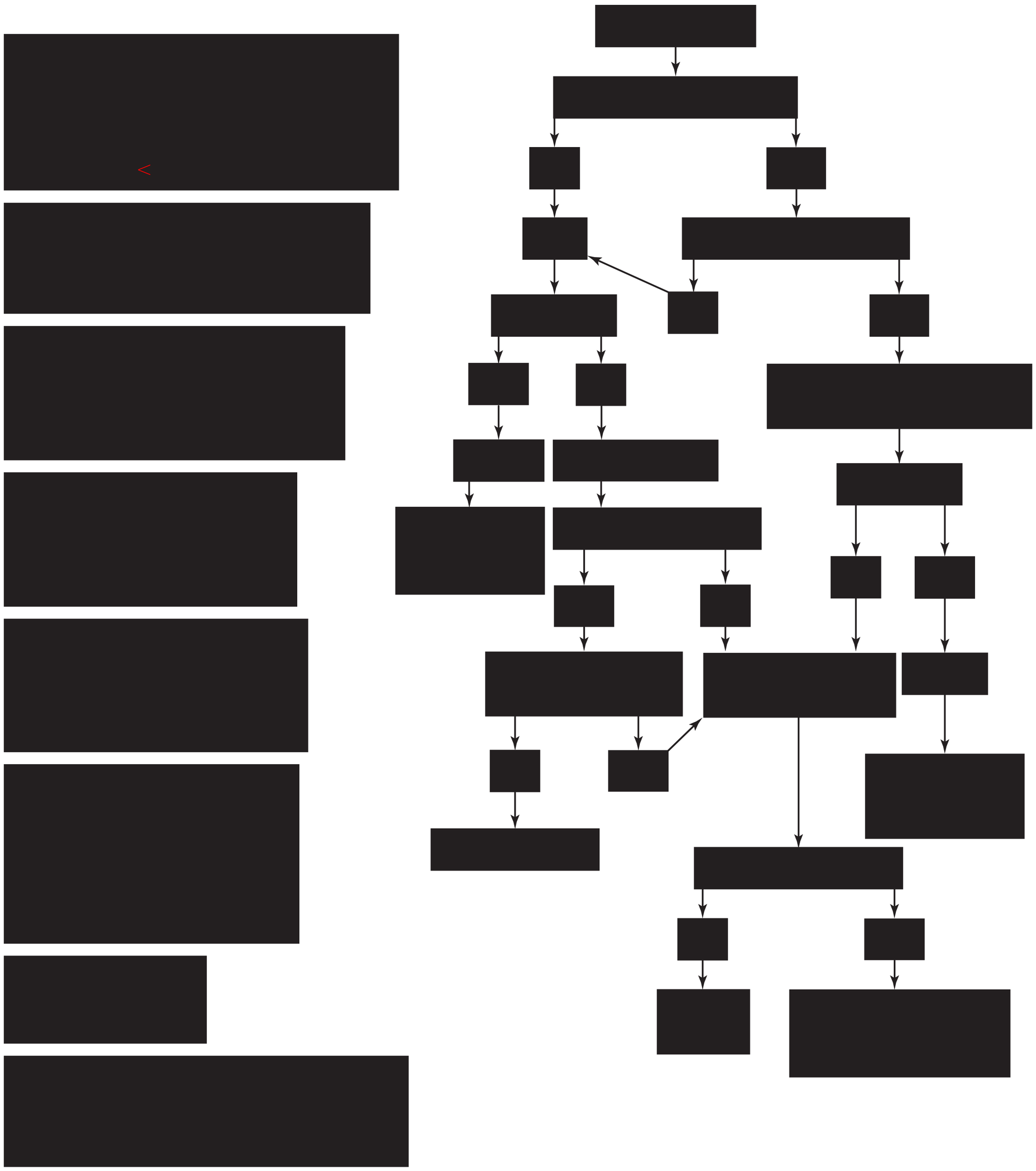


FIGURE 49-2 Approach to airway management in the conscious, critically ill. Abbreviations: NIVPPV, non-invasive positive pressure ventilation; RSI, rapid sequence intubation, BMV, bag mask ventilation; LMA, laryngeal mask airway; PEEP, positive end expiratory pressure.

mask ventilation after failed attempts at intubation may be difficult in patients with respiratory failure due to poor lung compliance and may cause gastric insufflation and regurgitation in nonfasted patients. RSI may reduce the risk of regurgitation and aspiration, improve intubating conditions, and allow for easier insertion of accessory and rescue devices, making it the technique of choice for many critically ill patients.[21–24] The specific device used in cases of difficult intubation will depend on the clinical circumstances, operator experience, and equipment available at different institutions. It bears mentioning that a single approach will not be effective in all circumstances, and clinicians should be familiar with different devices and techniques that can be used in different situations. After

a failed attempt at intubation, the next attempt should involve a more experienced provider or an alternative technique or device rather than repeating the same failed approach and expecting a different result.

COMPLICATIONS

The critically ill have higher complication rates than a patient undergoing elective intubation, and two of the most common complications are hypotension and hypoxia. Postintubation hypotension can occur for a number of reasons. Positive intrathoracic pressure from mechanical ventilation will cause a decrease in preload in hypovolemic patients, resulting in hypotension. In hypovolemic patients, adequate intravenous access should be obtained and fluid boluses started prior to intubation if time permits. In patients with vasodilatory shock (eg, sepsis or anaphylaxis), the administration of an induction agent may reduce the patient's compensatory sympathetic tone and cause vasodilation, resulting in cardiovascular collapse. In this case, hypotension can be avoided by using a lower dose of induction agent or with the use of vasopressor agents. Hypotension may also result from hyperventilation. After intubation, the patient is often "bagged" vigorously in a well-intentioned attempt to improve the oxygen saturation or to correct acidosis. Particularly in patients with exacerbations of chronic obstructive pulmonary disease or asthma, hyperventilation can lead to air trapping, increased intrathoracic pressure, and decreased venous return to the heart, thus resulting in hypotension and ultimately cardiac arrest.[25] A brief pause in ventilation (30 seconds), which allows the patient to fully exhale, may help to remedy the situation.

Hypoxia is common after intubation in the critically ill. The critically ill have poor physiologic reserve and undergo oxygen desaturation much more rapidly than those with normal cardiopulmonary function during periods of apnea. In addition, patients with refractory hypoxia prior to intubation often develop atelectasis when placed in the supine position and sedated and paralyzed, causing worsening hypoxia. Measures to improve postintubation hypoxia include elevating the head of the bed from the supine position, using higher levels of FiO_2, and the application of increasing levels of positive end expiratory pressure.

SPECIFIC CLINICAL CONDITION: POSTEXTUBATION LARYNGEAL EDEMA

Laryngeal edema is a common cause of upper airway obstruction in ICU patients. The condition results from trauma to the larynx and supraglottic tissue during intubation and from pressure and ischemia from the endotracheal tube. Although some degree of laryngeal edema occurs in most patients after tracheal intubation, only a small percentage develop clinically significant airway obstruction after extubation. The absence of a "cuff leak," or a lack of air freely passing around a deflated endotracheal tube, can help confirm the diagnosis of laryngeal edema prior to extubation. If laryngeal edema is suspected, the patient should be treated with glucocorticoids for 24 hours prior to extubation. Extubating the patient over an exchange catheter can often help facilitate reintubation if necessary.

Most patients who are reintubated for postextubation laryngeal edema typically develop symptoms within the first 30 minutes after extubation. Severe laryngeal edema is generally characterized by stridor and respiratory distress. Initial treatment involves intravenous glucocorticoids and nebulized epinephrine. Although only 1% to 4% of patients extubated in the ICU will require reintubation due to laryngeal edema, securing the airway may prove difficult.[26] Reintubation should be performed early before the airway becomes completely obstructed and intubation becomes impossible. We recommend the use of fiberoptic or optic guidance in a spontaneously breathing patient whenever possible. If attempts fail, a surgical approach will be necessary.

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CHAPTER 50

Airway Management in Emergency Medicine

Paul Phrampus and Sarah Parker

INTRODUCTION

Airway management is a critical aspect of the practice of emergency medicine and the emergency department (ED) presents a unique and challenging environment for airway management. The undifferentiated nature of the patients demands proficiency on the part of the clinician as well as familiarity with a wide range of equipment and procedures as well as adherence to best practices that have been identified for emergency airway management.

SETTING

Patients arriving at the ED in extremis are often unannounced and many times have little accompanying history or clinical information. This challenge is quite different from the elective surgical patient from whom a complete history can be acquired and a physical examination can be conducted in a low-stress environment to develop a plan for operative airway management.

In an ED one of the primary issues when evaluating a patient is the decision to intubate. Clinical indications requiring emergency airway management are diverse but revolve around the need to protect the airway of the patient who is otherwise unable to maintain a patent airway, or to provide invasive positive- pressure oxygenation, ventilation, or both to the critically ill.

Patients presenting with pathology such as allergic reactions, respiratory distress, cardiac arrest, burns, decreased levels of consciousness, and multisystems traumatic injury are common in the nearly 120 million ED visits that occur annually in the United States alone. It is estimated that 67% of intubations are performed for medical emergencies and 26% for traumatic emergencies (Fig. 50-1).[1]

Select populations of patients are candidates for noninvasive positive- pressure ventilation (see Chapter 3). This technology is contraindicated in patients who are unable to protect their airway, have a cardiac arrest, severely impaired consciousness, facial deformities secondary to trauma or surgery, high aspiration risk, and recent esophageal anastomosis. However, in patients with chronic obstructive pulmonary disease (COPD), asthma, hypoxemic respiratory failure, or cardiogenic and noncardiogenic pulmonary edema without the above contraindications, it can be a useful adjunct to preventing intubation. A Cochrane database review of 14 studies showed that the use of noninvasive positive- pressure ventilation in patients with COPD decreased mortality, need for intubation, respiratory rate, length of hospital stay, and complications with treatment.[2]

AIRWAY ASSESSMENT

When intubation is deemed necessary in the ED, it is prudent to decide that every airway is going to be a difficult airway and plan accordingly (see Chapter 12). It is estimated that up to 20% of ED intubations can be classified as difficult.[3] Unlike the operating room, there is often no time to do an adequate physical examination of the emergency airway, and patient history can be limited. A rapid examination of the head and neck can help to show characteristics that can be suggestive of a difficult airway. Many patients necessitating an emergency airway have decreased level of consciousness and are unable to assist with the examination, such as assessing the size of the mouth opening and flexibility of the neck. In addition, patients can be limited to the prone position. In a retrospective review of ED intubations, Levitan et al concluded that in only one-third of patients could a Mallampati score, thyromental distance, and neck mobility be properly assessed.[4] However, other anatomic abnormalities, including short neck, small chin, obesity, facial trauma, presence of facial hair, and neck scars can be assessed in predicting the degree of difficulty in establishing bag mask ventilation and in performing direct laryngoscopy (Fig. 50-2).

Unlike the routine preparations for cases of elective intubations, patients presenting to the ED must be presumed to have a full stomach. This fact requires the emergency physician to consider the risks of gastric content aspiration into the management of airways in the ED.

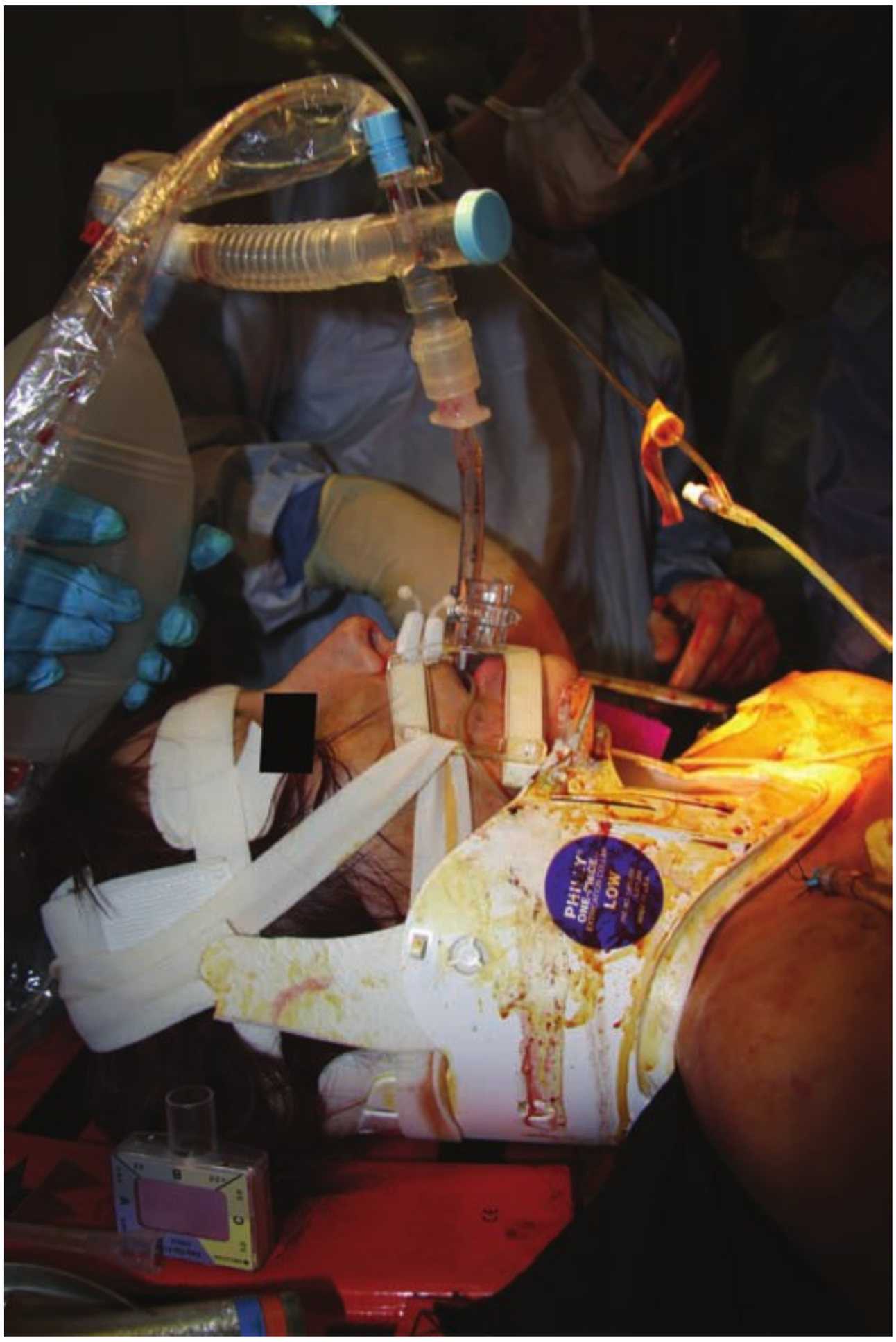


FIGURE 50-1 A patient who was intubated in the trauma resuscitation area requiring maintenance of cervical spine precautions.



FIGURE 50-2 Intubating a patient in the ED with a videolaryngoscope. The patient had a large head, short neck, decreased thyromental distance, and a difficult to palpate cricothyroid membrane.



FIGURE 50-3 A trauma patient arrives at the ED after failed intubation in the field where prehospital care providers placed a King LT (laryngeal tube) airway.

Initial ED management of the airway included blind nasal tracheal intubations. However, in the 1980s, Dronen et al performed a prospective randomized control trial of blind nasal tracheal intubation versus rapid sequence induction and endotracheal intubation in the ED setting. He showed that rapid sequence intubation was more successful (100% vs 65%), required less attempts (1.3 vs 3.7), was faster (64 vs 276seconds), and had fewer complications. Since that time, rapid sequence induction has been recognized as the safest, most efficient choice for ED intubations.[5] This technique uses a combination of sedative and muscle relaxants with a rapid onset and short half-life that creates a favorable physiologic situation to facilitate endotracheal intubation via direct laryngoscopy (see Chapter 8).

EQUIPMENT

Multisystem trauma patients are another category of airway challenges unique to the ED. Distortions of normal anatomy from swelling, bony or soft tissue injury along with bleeding, burns, foreign bodies, and vomiting can occur. In addition, all trauma patients are presumed to have a cervical spine injury and require strict spinal immobilization precautions. Cervical spinal immobilization prevents the ideal positioning of the patient for direct laryngoscopy, and thus such cases should be automatically regarded as a potential for a difficult airway or at a minimum a difficult laryngoscopy. Such a trauma patient requiring endotracheal intubation must be handled in a way that reduces or eliminates potential movement of the cervical spine. New technology, such as videolaryngoscopy (see Chapter 24), which includes the GlideScope (Verathon Inc, Bothell, Washington, USA) and Storz C-mac (Karl Storz & Company, Tuttlingen, Germany) devices, has become a very useful adjunct in trauma airways. With limited mobility of the neck, videolaryngoscopy provides a more anterior view than direct laryngoscopy, which can facilitate endotracheal tube placement.

Given the emergent need for airway management, coupled with the many limitations faced by the emergency physician, including limited patient history, cervical spine immobilization, facial trauma, and presumed full stomach, it is imperative to always have a backup plan if the first attempt at intubation fails. A multicenter report of emergency intubations suggests that 95% of intubations are successful the first time in the ED, and intubation is ultimately 99% successful.[1,6] In addition to standard laryngoscopy equipment, most EDs have a difficult airway cart that is stocked with airway stylets/bougies, laryngeal mask airways (LMAs), intubating LMAs, esophageal-tracheal Combitubes (Tyco-Kendall, Mansfield, Massachusetts, USA) or other supraglottic rescue devices (such as the King airway, King Systems, Noblesville, Indiana, USA), and a cricothyrotomy kit. In the prehospital setting, LMAs/Combitubes/King airways are frequently used when standard endotracheal intubation fails, with success rates of ventilation approximating 100%, negating the need for a surgical airway in the field (Fig. 50-3). Of the patients who survive to hospital admission and for whom follow-up data is available, 40% require emergent tracheostomy for definitive airway placement.[7] However, in ED airway management, adjuncts are rarely deployed as rescue devices.[8] A surgical airway is performed in only 0.84% of all cases and 1.7% of trauma cases.[1] It is believed the decline in rescue techniques and surgical airways are secondary to the success of rapid sequence intubation.

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PART XV

Common Patient Conditions Requiring Specialized Approach to the Airway

CHAPTER 51

Obstructive Sleep Apnea and Airway Management

Audra Webber and Kathirvel Subramanian

Obstructive sleep apnea (OSA) is a sleep disorder[1] characterized by a decrease in upper airway patency and size during sleep. Patients with OSA experience repeated instances of partial or complete airway obstruction that results in sleep disruption, hypercapnia, and hypoxemia. OSA can lead to numerous comorbidities, including hypertension (HTN), arrhythmias, and gastroesophageal reflux disease (GERD). Additionally, the increased sympathetic output and tone experienced by these patients[2] can contribute to the metabolic syndrome. OSA occurs in both children and adults but varies by etiology in these two groups.

The gold standard of OSA diagnosis is polysomnography, from which is derived the apnea-hypopnea index (number of breathing cessations and partial obstructions per hour of sleep). The severity of OSA, (mild, moderate, or severe) is based upon this index. This diagnostic scheme applies to both children and adults.

PEDIATRIC OSA

The incidence of sleep apnea in the pediatric patient population is approximately 1% to 3%. The most common level of obstruction of the airway during rest is at the base of the tongue and soft palate.[3] OSA in children is most commonly associated with enlarged tonsils and adenoids. The degree of hypertrophy does not correspond clinically with the severity of OSA. However, OSA is a multifactorial disorder and is also associated with craniofacial anomalies as well as syndromes that cause decreased pharyngeal tone such as Down Syndrome.[4] Shwengel et al,[4] in a review, describe the pediatric OSA patient population as having a peak at 2 to 6 years of age, no gender predominance, and a weak association with obesity in decades past. However, with childhood obesity on the rise, the association of pediatric OSA with obesity has grown. There are numerous physiologic consequences of OSA in children (Table 51-1). Surgical excision of the enlarged tonsils and adenoids is generally definitive therapy in this population. However, obese children can still be at risk for OSA even after adenotonsillectomy.[4]

Clinicians with a responsibility for airway management are most likely to encounter a child with OSA when he/she presents for adenotonsillectomy. However, one may be required to care for a child with undiagnosed OSA in other settings as well, including other operative procedures. Hence, for elective pediatric procedures requiring sedation or airway management, a thorough airway examination and questioning about nighttime snoring are warranted. Snoring is a sensitive marker for OSA in children. Pediatric patients have very little oxygen reserve at baseline and patients with OSA even less so. Preoxygenation is one of the key strategies for a safe induction of anesthesia (Table 51-2). In pediatric patients with adenotonsillar hypertrophy and therefore suspected OSA, it has been shown that lateral positioning in combination with chin lift and jaw thrust provide improved airway patency for anesthetized children.[5]

ADULT OSA

OSA is far more common in adults than in children (Figs. 51-1–51-11). This disorder has an incidence in the adult population of approximately 1 in 4 men and 1 in 10 women.[6] Only a small percentage of these patients carry an official polysomnographic diagnosis of OSA. Most of the adults with OSA are undiagnosed. Therefore, the undiagnosed OSA patient will be the one most frequently encountered preoperatively. In the perioperative setting, these patients will present for all types of surgery, not solely airway surgery. In the elective situation, a high index of suspicion for OSA will serve the clinician well, as well as the judicious use of OSA-specific questionnaires. OSA is strongly associated with obesity, and the more obese the patient the more likely the incidence of OSA. Obesity results in fatty deposits in the tongue and upper airway,

which reduce lumen diameter and increase the likelihood of obstruction of the upper airway.[6] There are anatomical differences in the pharyngeal airway between OSA patients and controls. OSA patients have increased total fat volume surrounding the pharyngeal airway and greater airway collapsibility.[7] Additionally, nonobese OSA patients may have a shorter mandible, inferior hyoid, and retrognathic maxilla.[8] CT and MRI studies have shown OSA patients have a smaller airway lumen than controls. Neck circumference, male gender, and craniofacial anomalies also predispose the patient to OSA (Table 51-3). Snoring is a very sensitive but nonspecific indicator of OSA.

In adults, OSA is associated with multiple morbidities, and these are much more prevalent than in children. These include cardiovascular disease, heart failure, arrhythmias, hypertension, cerebrovascular disease, metabolic syndrome, and gastroesophageal reflux disease.

OSA patients can present unique difficulties to the anesthesiologist with regard to the induction of and emergence from anesthesia (Table 51-4). During the perioperative period, numerous studies have demonstrated OSA patients to have a potential for upper airway collapse, exacerbation of hypoxemia and hypercapnia, cardiac arrhythmia and difficulty with airway management.[9] These patients are more susceptible to anxiolytics, sedatives, and opioids as well as to general anesthetic agents. There is a dose-dependent depression of muscle activity in the normal upper airway with IV sedative and inhaled anesthetic agents that results in increased collapsibility. This effect is enhanced and even exaggerated in patients with OSA.[9] Therefore, relatively small doses of sedation may rapidly result in apnea in this population. There is some evidence for use of continuous positive airway pressure (CPAP) obviating the enhanced effects of sedation and opioid

Table 51-1

Consequences of OSA in the Pediatric Population

1. Increased pharyngeal collapsibility
2. Increased likelihood of difficult airway
3. Increased sensitivity to opioids
4. Decreased response to hypercarbia and negative pressure
5. Pulmonary HTN
6. Cardiac dysfunction that may eventually lead to corpulmonale
7. Impaired growth, possibly due to increased work of breathing

From Schwengel DA, Sterni LM, Tunkel DE, et al. Perioperative management of children with obstructive sleep apnea. *Anesth Analg.* 2009;109(1):60–75 with permission.

Table 51-2

Perioperative Issues and Strategies in Pediatric OSA Patients

1. Adequate preoxygenation should be administered in a spontaneously breathing patient before induction of anesthesia.
2. Inhaled induction with a volatile agent relaxes the genioglossus muscle and may result in airway collapse and obstruction in the OSA patient. Consider:
   a. Position lateral or upright
   b. Jaw thrust
   c. Positive pressure by mask
   d. Oral airway
3. Sedatives should be given sparingly, and always under monitored care—consider nonsedating medications such as ketamine or dexmedetomidine.
4. IV induction may be preferred in severe OSA patients to avoid upper airway obstruction during spontaneous ventilation in the anesthetized patient.
5. Alternative means of managing the airway should be available for emergent situations, when ventilation or intubation is impossible, as per the ASA Difficult Airway Algorithm.
6. If airway swelling is anticipated, intravenous steroids should be administered.
7. Extubation should occur only after the patient is fully awake.
8. A nasopharyngeal airway may be placed prior to extubation.
9. Supplemental oxygen should be used during any time that the patient is sedated.

From Schwengel DA, Sterni LM, Tunkel DE, et al. Perioperative management of children with obstructive sleep apnea. *Anesth Analg.* 2009;109(1): 60–75 with permission.

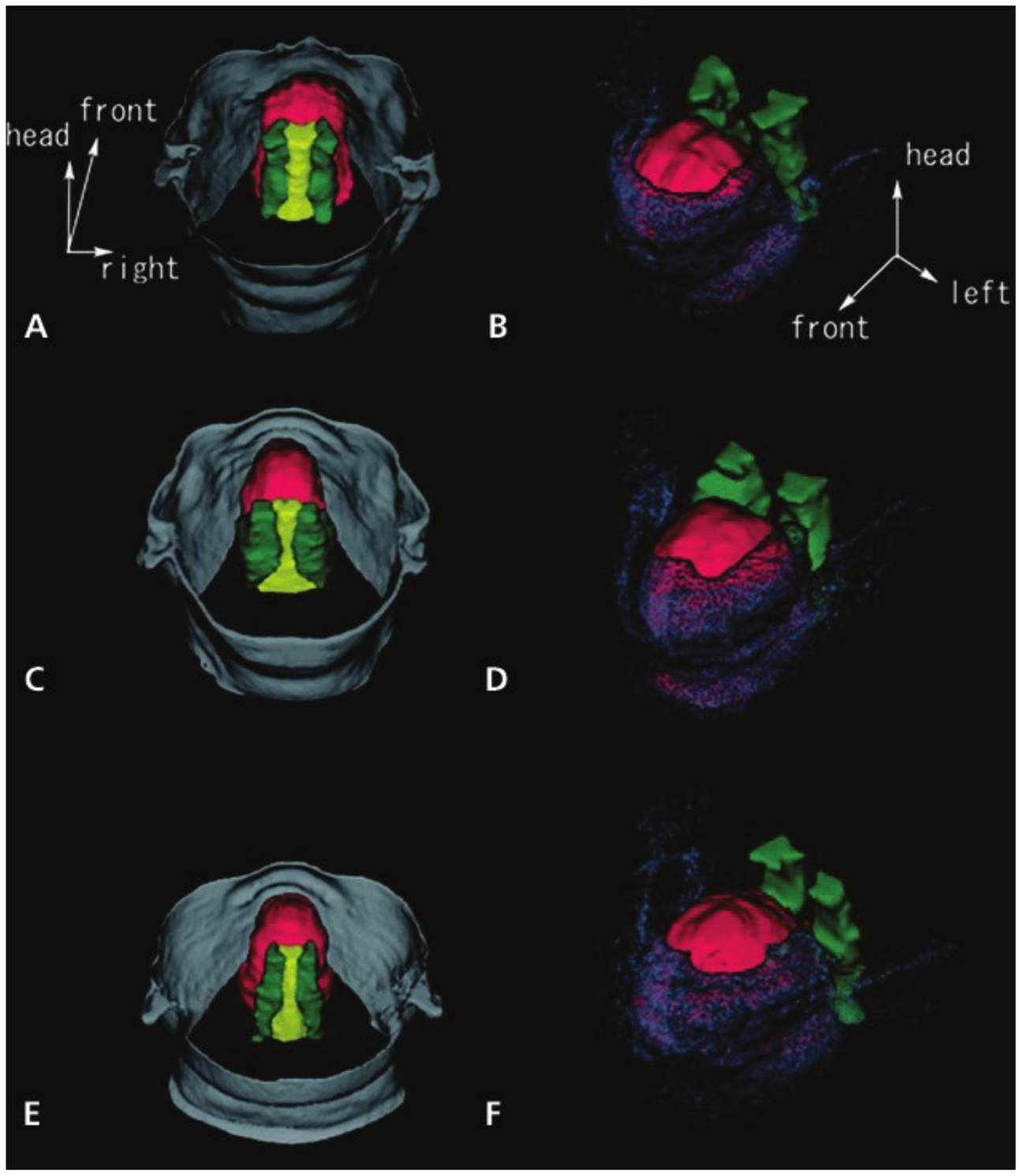


FIGURE 51-1 Three-dimensional magnetic resonance imaging reconstructions of subjects with **(A, B)** positional obstructive sleep apnea syndrome (OSAS); **C, D:** nonpositional OSAS; and **E, F:** control subjects. **A, C, E:** Lateral pharyngeal wall, tongue, and pharyngeal airway with outline of the face, posterosuperior view; **B, D, F:** lateral pharyngeal wall, tongue, and craniofacial structures (mandible and lower part of maxilla), anterosuperior left oblique view. Green, lateral pharyngeal wall; red, tongue; yellow, upper airway space; blue web, craniofacial structures. Note that positional OSAS had relatively small volume of the lateral pharyngeal wall and the smallest craniofacial volume; nonpositional OSAS had relatively large craniofacial volume and the largest volume of the lateral pharyngeal wall; the control subjects had the largest craniofacial volume and the smallest volume of the lateral pharyngeal wall.

From Saigusa H, Suzuki M, Higurashi N, et al. Three-dimensional morphological analyses of positional dependence in patients with obstructive sleep apnea syndrome. Anesthesiology. 2009;110(4):885–890 with permission.

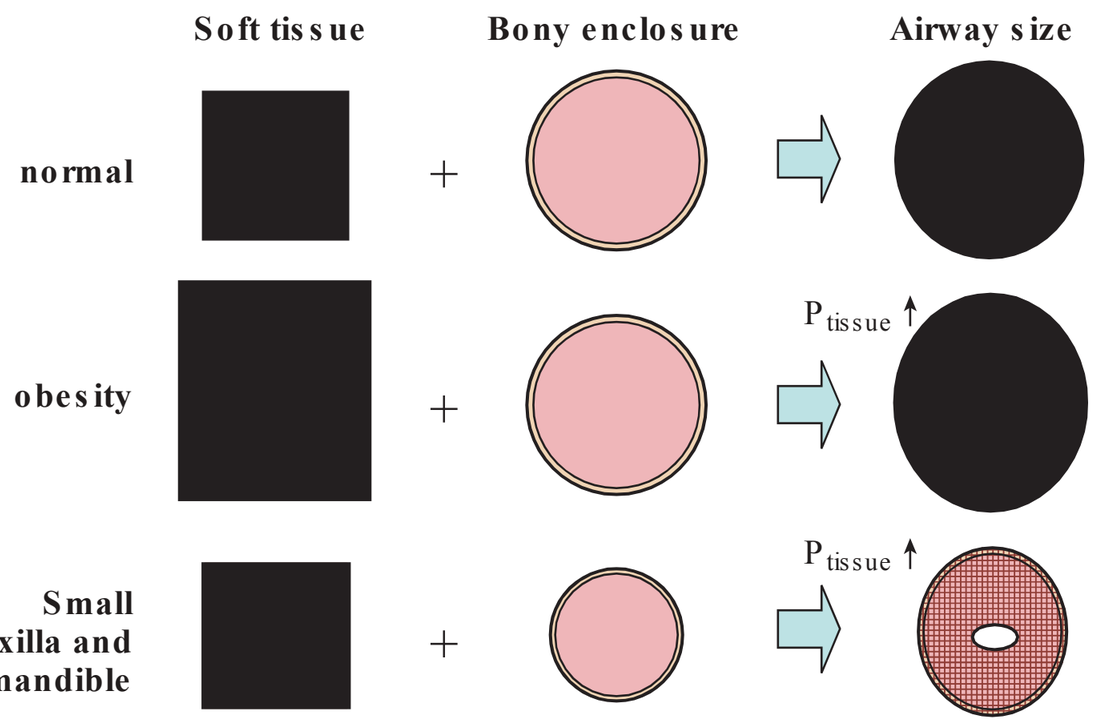


FIGURE 51-2 Schematic explanations for interaction between soft tissue surrounding the pharyngeal airway and craniofacial bony enclosure. The airway size is determined by the balance between amount of soft tissue and bony enclosure size. Ptissue, tissue pressure.

From Isono S. Obstructive sleep apnea of obese adults: pathophysiology and perioperative airway management. Anesthesiology. 2009;110(4):908–921 with permission.

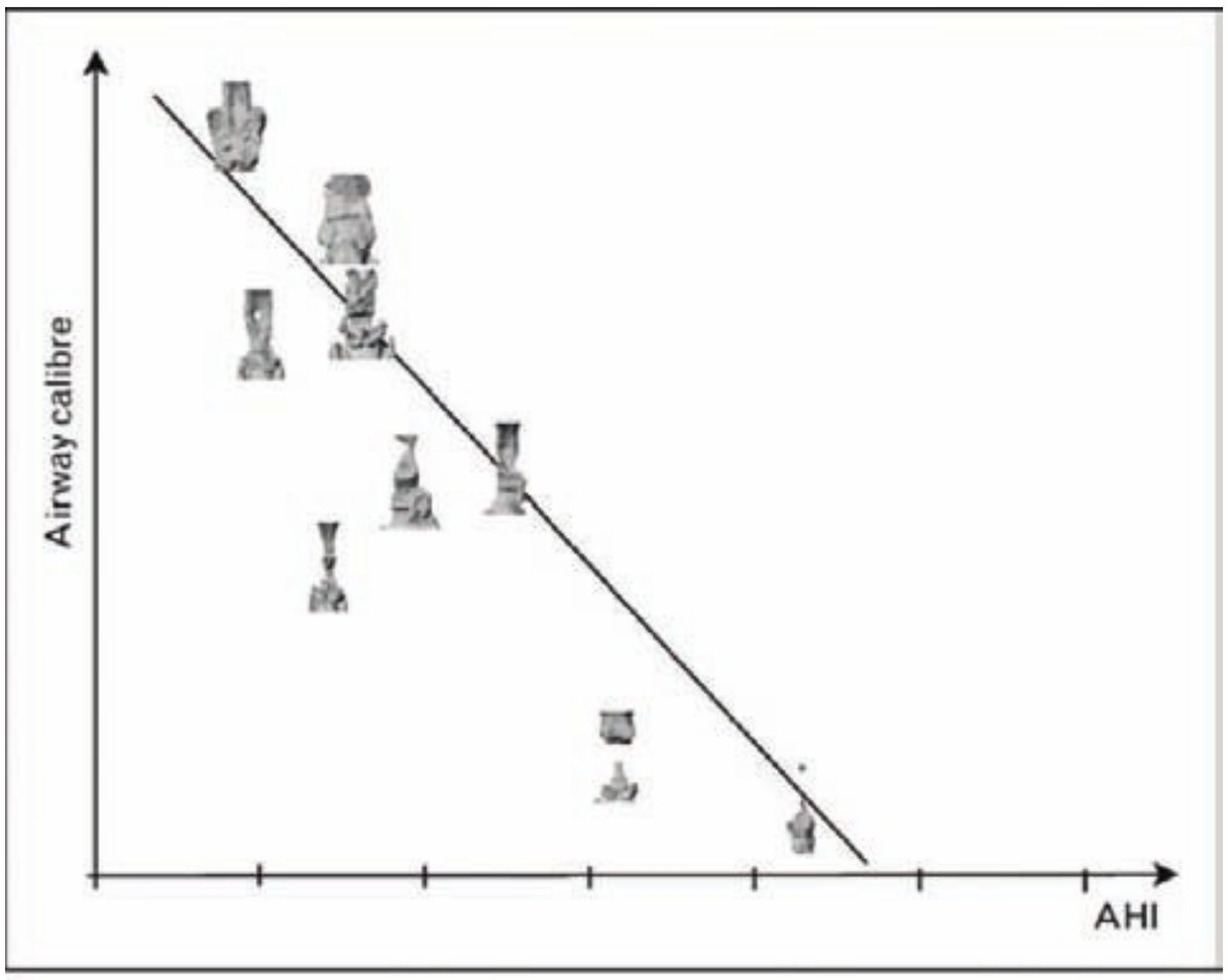


FIGURE 51-3 Pharyngeal airway lumen for different degrees of OSA.

From Vos WG, De Backer WA, Verhulst SL. Correlation between the severity of sleep apnea and upper airway morphology in pediatric and adult patients. Curr Opin Allergy Clin Immunol. 2010;10(1):26–33 with permission.

AHI, apnea-hypopnea index.

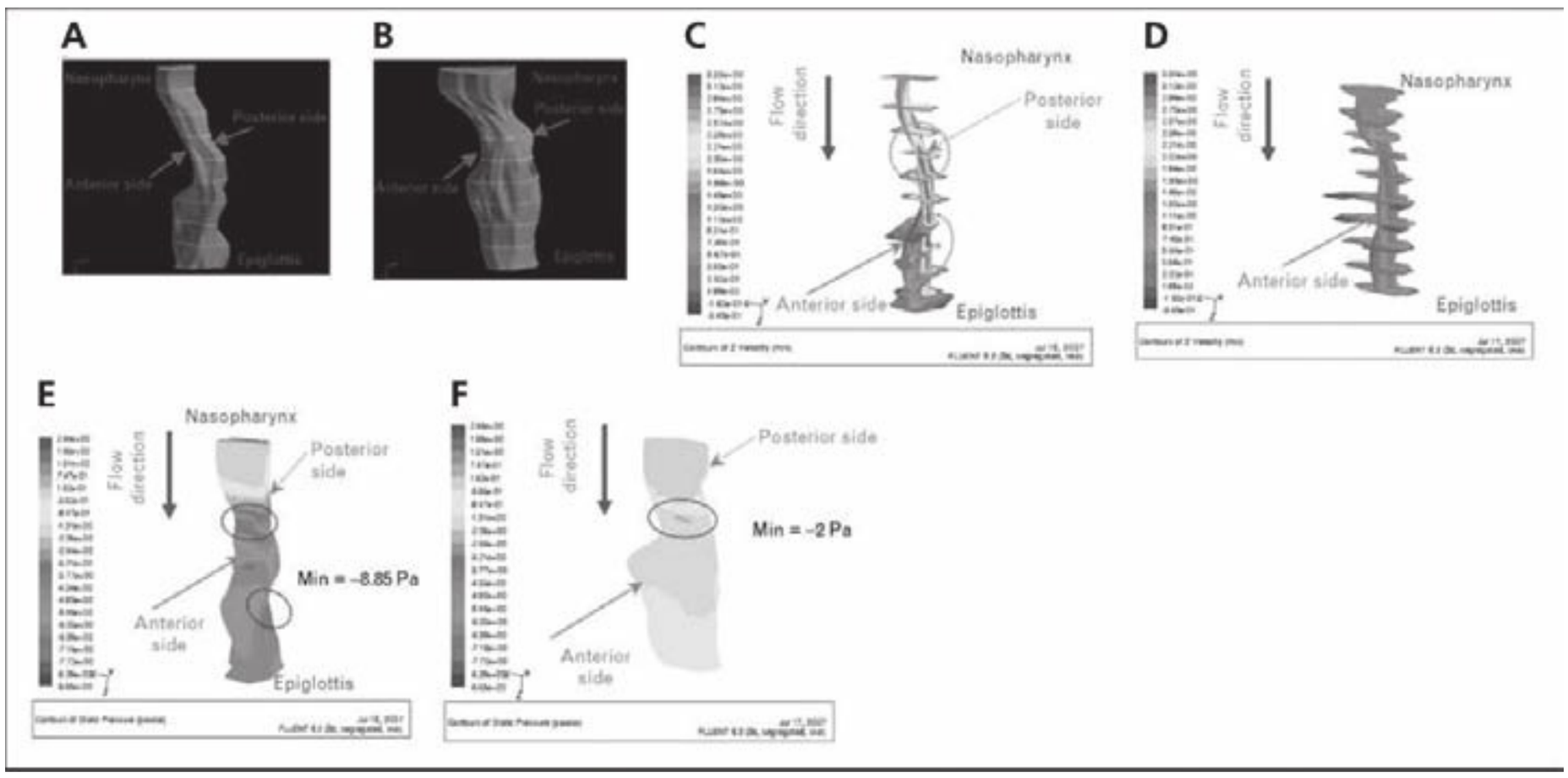


FIGURE 51-4 Three-dimensional reconstructed airway models before **(A)** and after **(B)** adenotonsillectomy. Axial velocity and static pressure distributions, respectively, before **(C and E)** and after **(D and F)** surgery. Highest velocity and lowest wall static pressure observed at the site of minimum cross-section in baseline (before) model. Surgery was found to increase the airway cross-section in the retropalatal pharynx.

From Vos WG, De Backer WA, Verhulst SL. Correlation between the severity of sleep apnea and upper airway morphology in pediatric and adult patients. Curr Opin Allergy Clin Immunol. 2010;10(1):26–33 with permission.

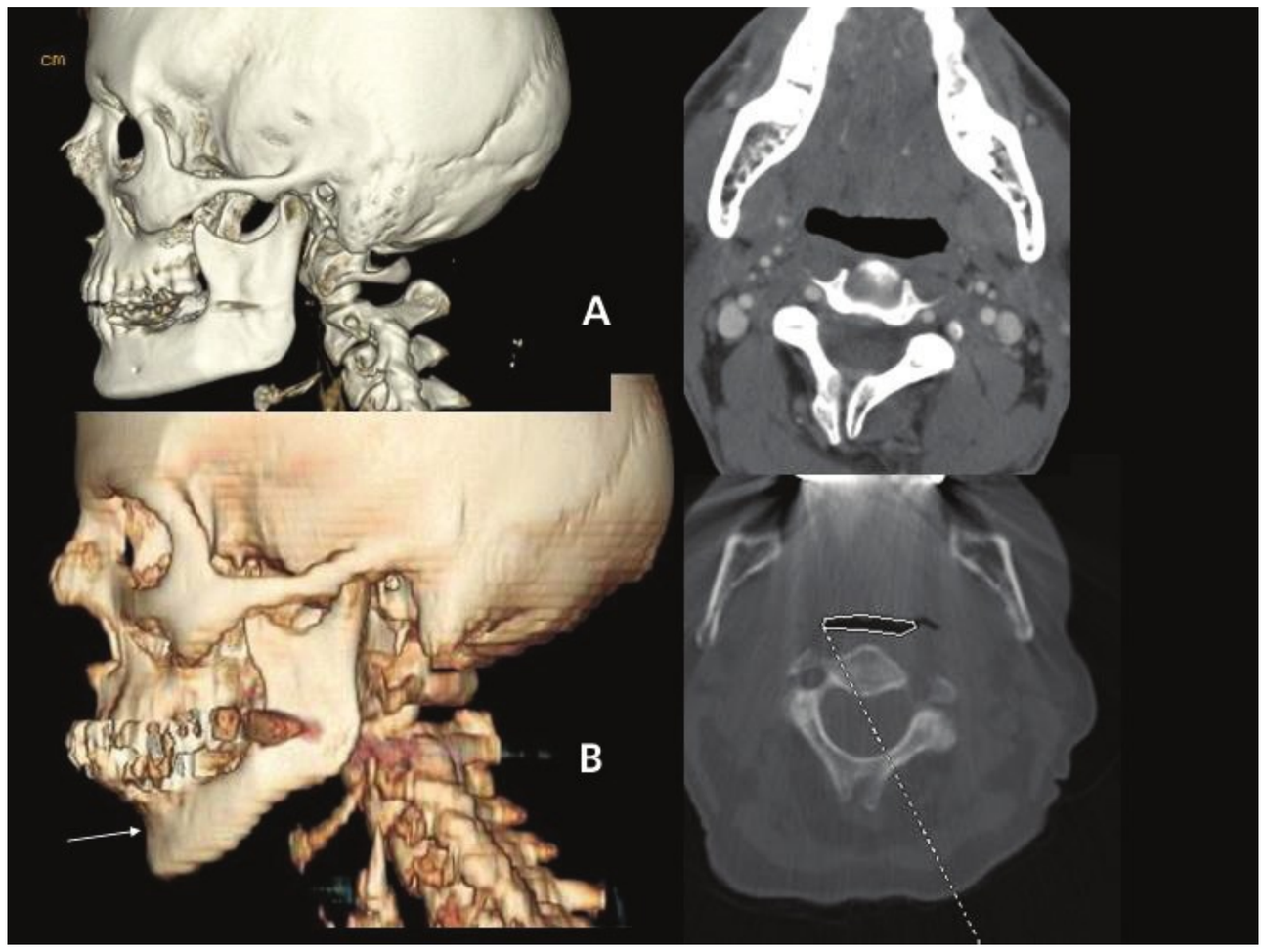


FIGURE 51-5 **A:** Normal Bone 3D VR image on the left with axial image through the retroglossal airway on the left. Note that the mandibular size is proportionate to the maxilla and orbits. **B:** This woman had a thin body habitus but had severe OSA. Note the recessed and small hypoplastic mandible (arrow) and marked narrowed retroglossal airway on the axial image.

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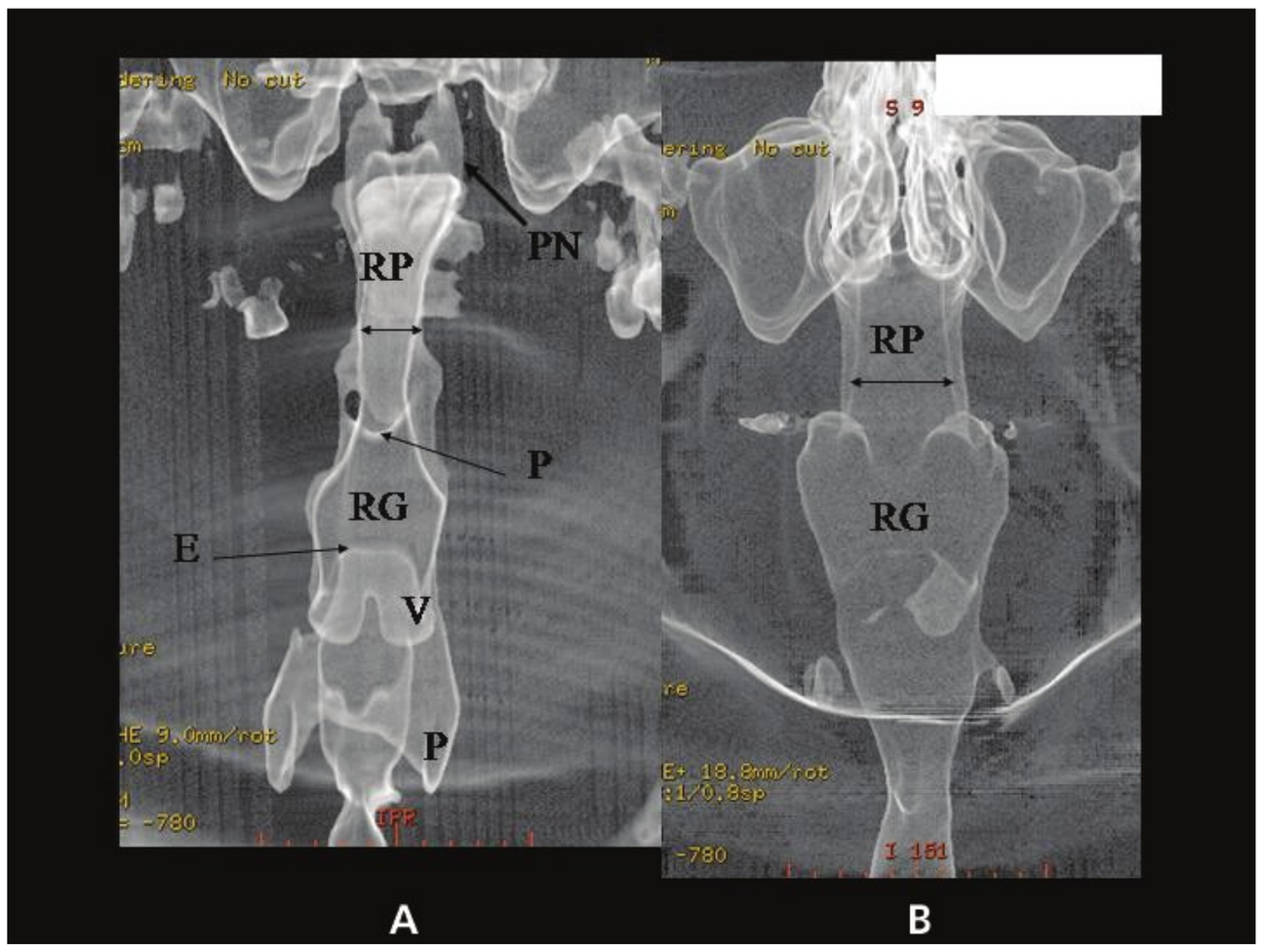


FIGURE 51-6 **A:** This patient has severe OSA with retropalatal and retroglossal narrowing. Note the narrowing of the transverse dimension (double-ended arrow) of the retropalatal airway (RP). The location of the tip of the palate (P) and mildly narrow edretroglossal airway (RG) is shown. The vallecula (V) is located at the anterior aspect of the hypopharynx and the piriform (P) sinuses are located posterolaterally. **B:** Normal view for comparison.

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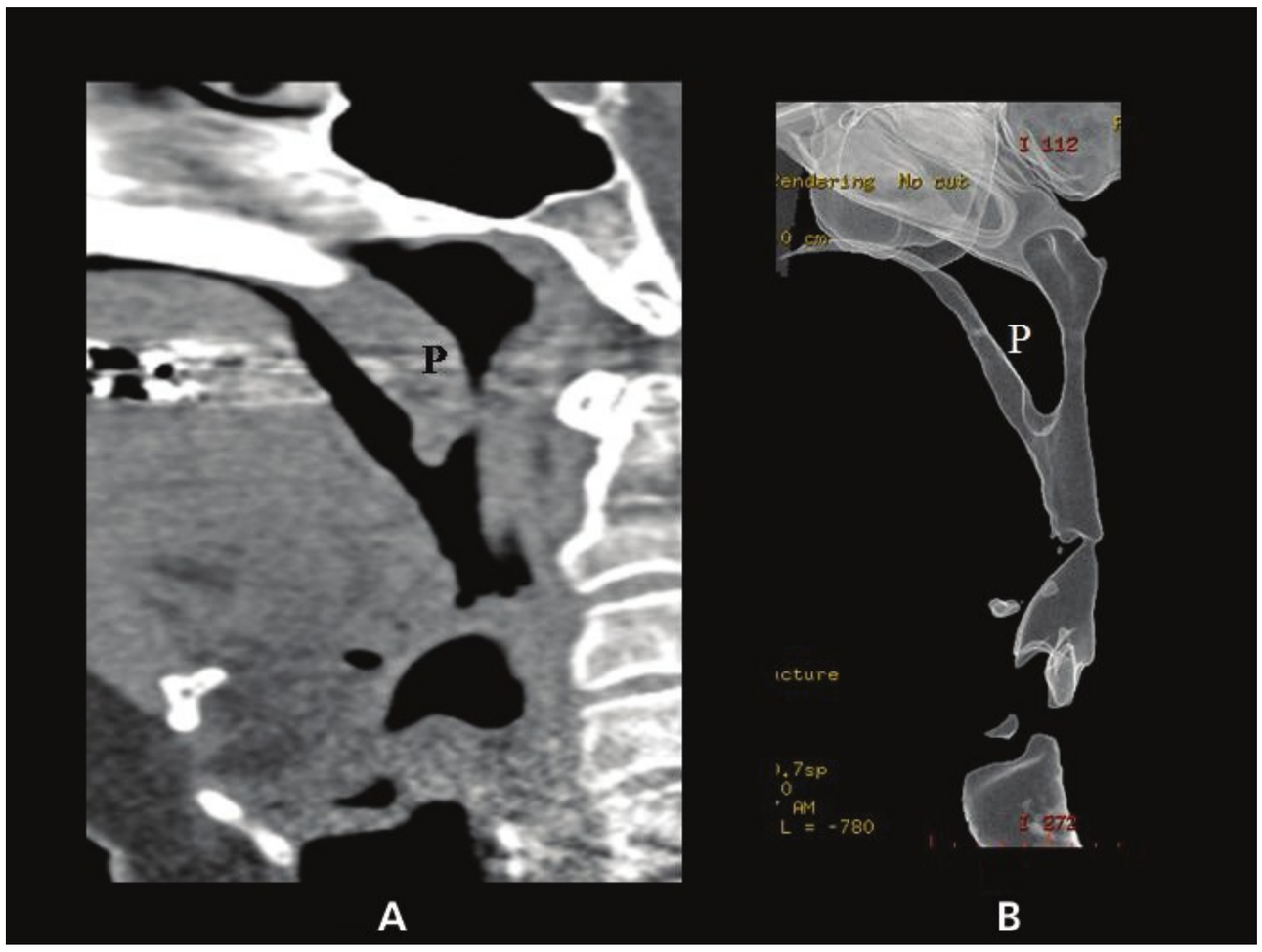


FIGURE 51-7 **A:** Sagittal reformat view shows the posterior displacement of the enlarged tongue. The palate (P) is also long and thickened contributing to narrowing of the airway. **B:** VR-ACS view shows the marked narrowing of the retroglossal airway even while the patient was awake.

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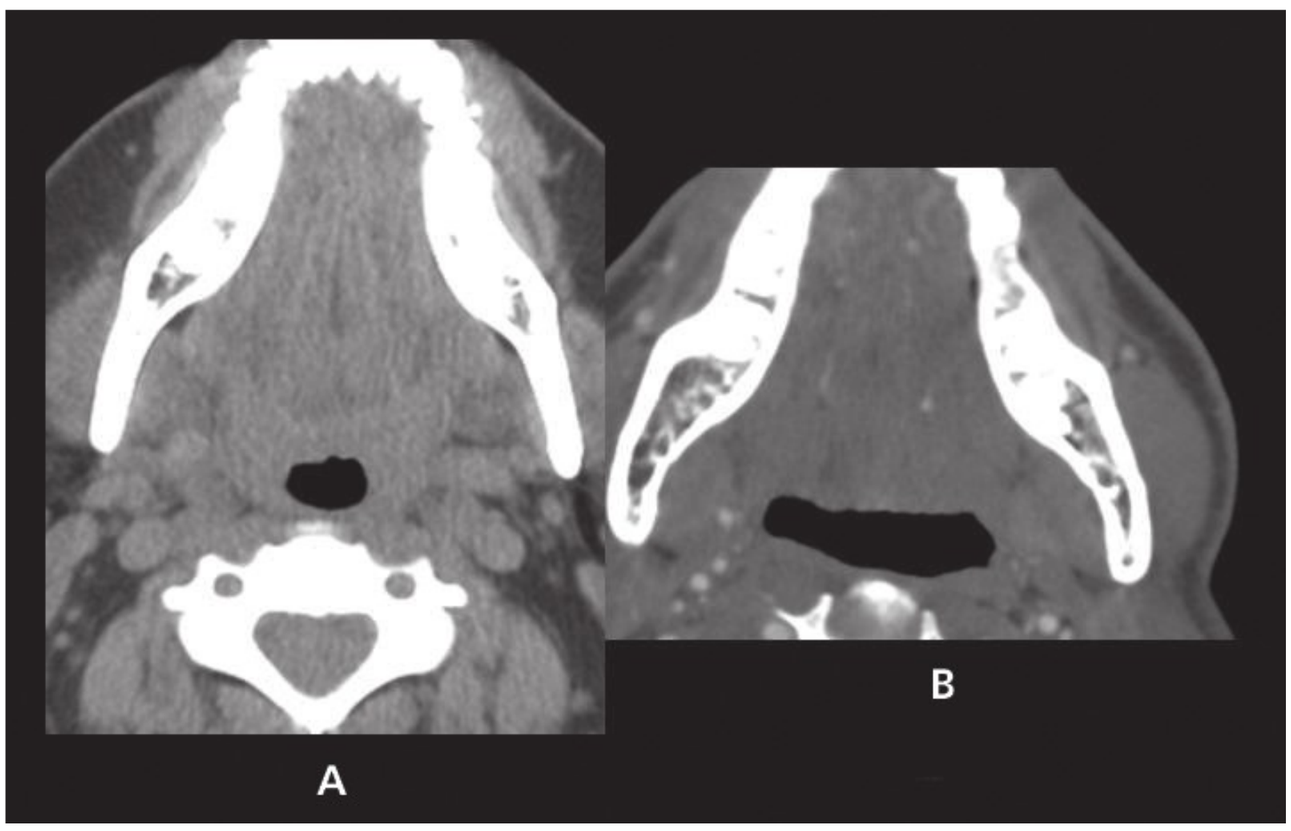


FIGURE 51-8 **A:** The soft tissues around the retroglossal airway are circumferentially thickened with resultant narrowing in this obese patient with OSA. The airway is round rather than the normal oval or rectangular shape. **B:** Normal retroglossal airway for comparison. The airway is more oval with patent lateral recesses.

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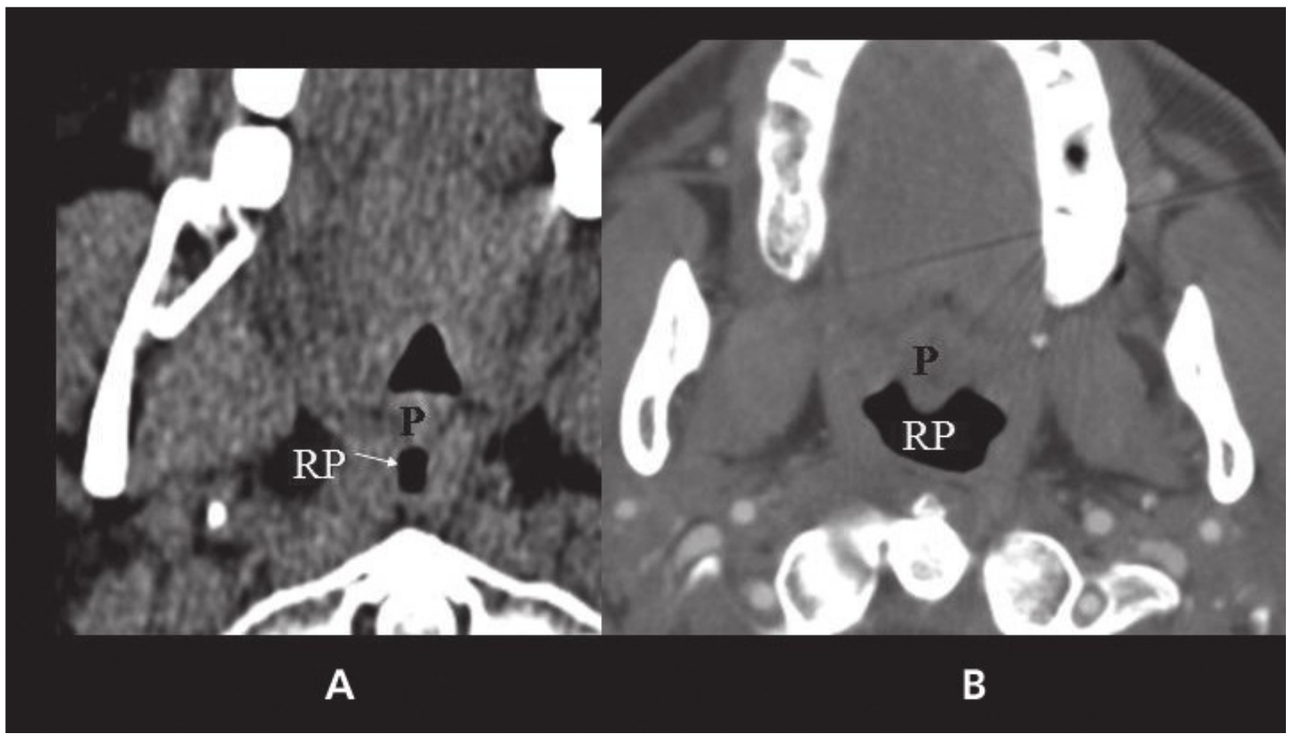


FIGURE 51-9 **A:** Severe retropalatal (RP) airway narrowing measuring less than 30 mm^2 posterior to palate (P). Patient has severe OSA diagnosed by polysomnography. **B:** Normal RP airway for comparison.

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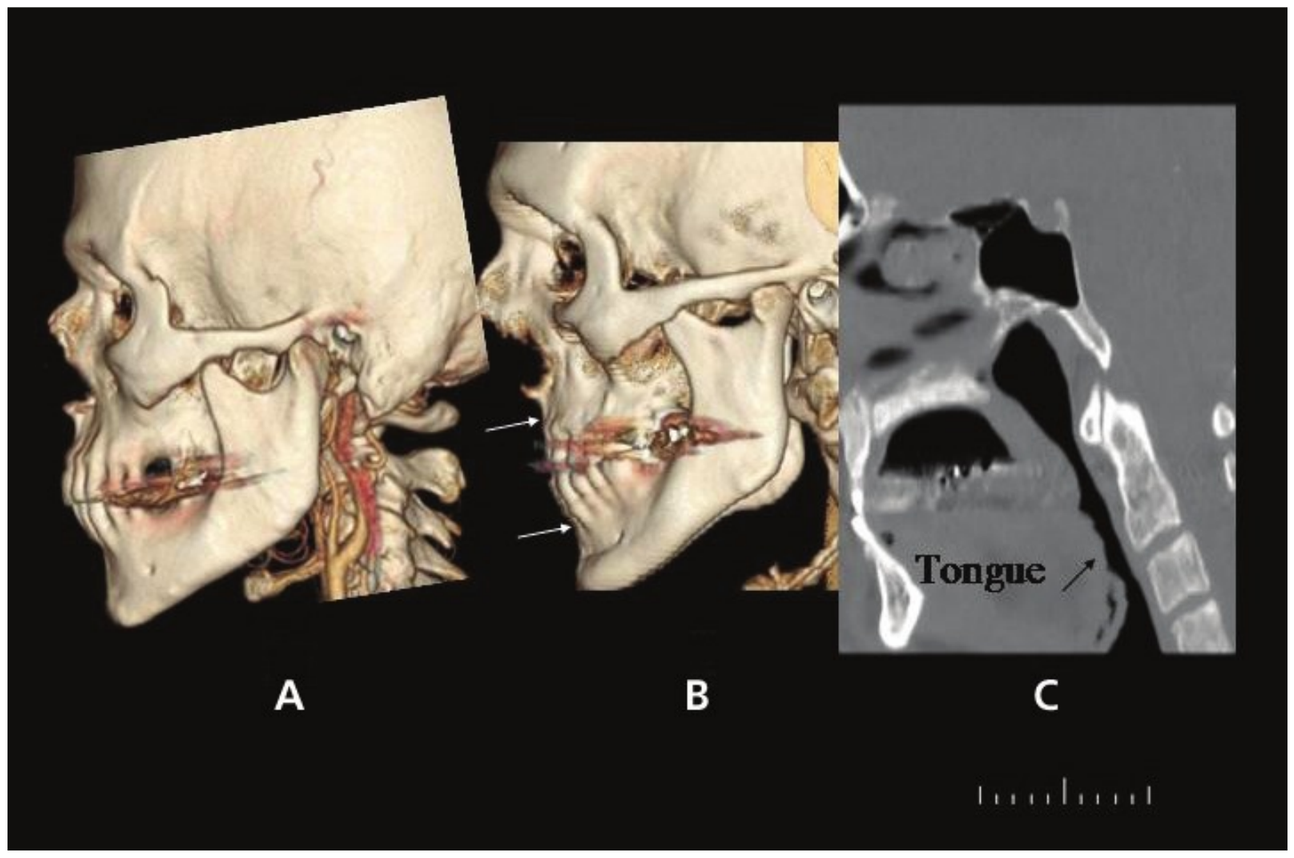


FIGURE 51-10 **A:** Normal VR 3D Bone side view. The maxilla and mandible are proportionate to the upper face and skull. **B:** Thin male with severe OSA. The maxilla and mandible are recessed and retrognathic (arrows). **C:** Sagittal reformat: Both the retroglossal and retropalatal airways are narrow. The tongue is too large for the mouth and narrows the airway.

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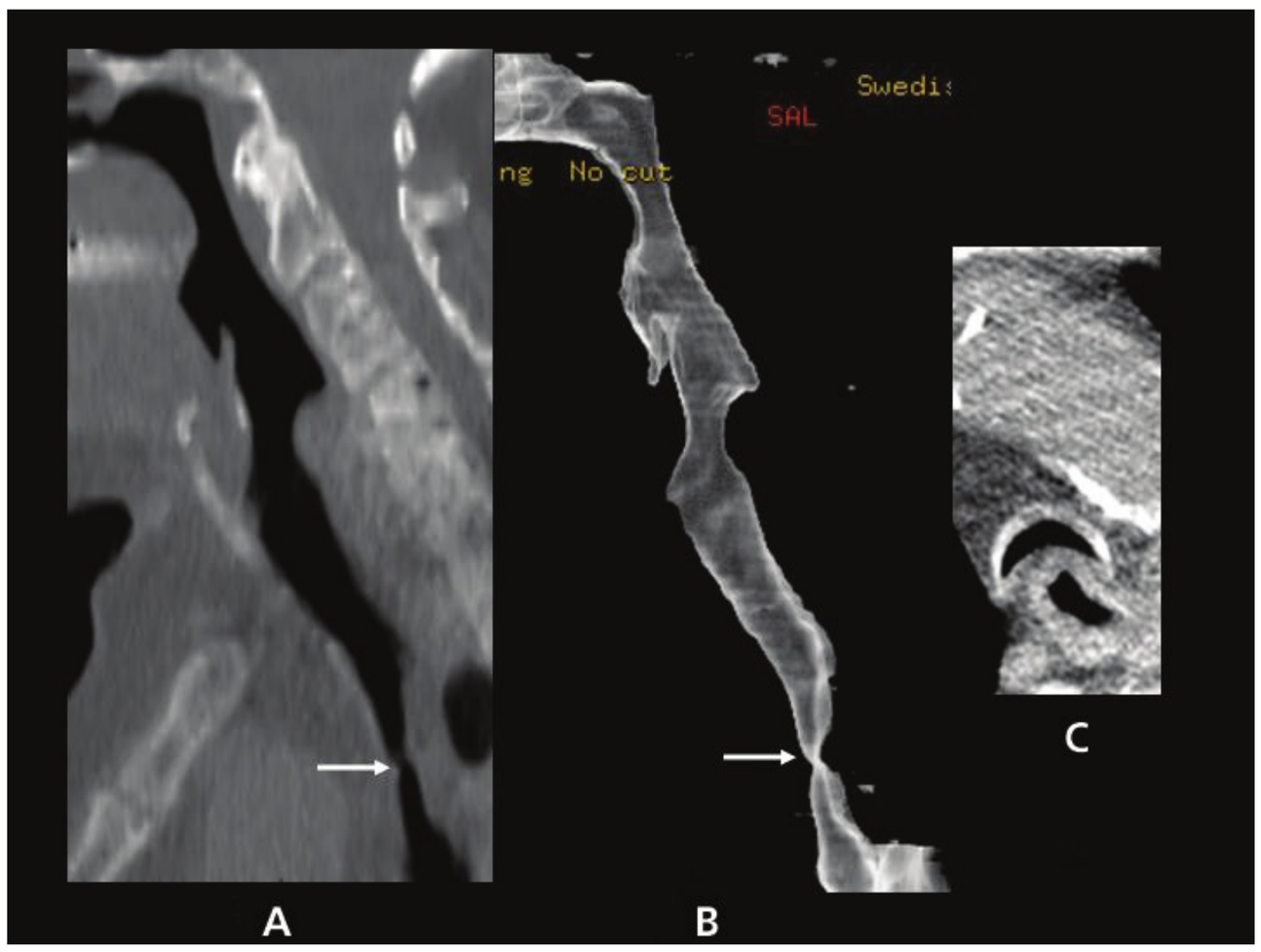


FIGURE 51-11 OSA due to tracheal stenosis (arrow) of intrathoracic trachea. **A:** Sagittal reformat. **B:** VR-ACS. **C:** Axial view.

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analgesia in OSA patients. Rennotte et al[10] examined diagnosed OSA surgical patients whose nasal-CPAP was used until intubation and resumed immediately after extubation, then used 24 to 48 hours postoperatively. These patients had no restrictions on analgesic, sedative, or anesthetic drugs and experienced no complications. However, more research is needed, and the efficacy of CPAP has not yet been established for the perioperative setting.[11]

Patients with OSA are approximately eight times more likely to be difficult to intubate than those without this disease.[6] However, with proper positioning (ie, ramping) this effect may be attenuated.[12] In direct relation to this, patients who are difficult to intubate have a higher likelihood of being diagnosed with OSA. In a recent study, Chung[11] reported that, in a group of unexpected difficult intubation patients referred for sleep studies postoperatively, 66% were diagnosed with OSA by polysomnography. OSA is a risk factor for difficult mask ventilation (MV)[7] though no exact numbers are available. Mandibular advancement[7] without an oral airway is not effective in obese patients. The practitioner should always consider difficult or impossible MV in obese patients with OSA and have an oral airway at the ready.

Those aspects of the patient airway that make one suspect the likelihood of difficult intubation are the same as those that predispose patients to OSA (Table 51-3). A thorough airway examination is always warranted. This is especially important in patients with diagnosed and

Table 51-3

Common Factors that Predispose to both OSA and Difficult Intubation or Ventilation

Predispoing Factors	Difficult Airway	OSA
Obesity	Yes	Yes
Increased neck circumference	Yes	Yes
Crowded oropharynx/high Mallampati score	Yes	Yes
Decreased neck extension	Yes	Yes
Limited mouth opening	Yes	Yes
Decreased thyromental distance/ mandibular hypoplasia	Yes	Yes

From Seet E, Chung F. Management of sleep apnea in adults—functional algorithms for the perioperative period: continuing professional development. *Can J Anaesth*. 2010;57(9):849–864 with permission.

Table 51-4

OSA: Perioperative Risks

1. Difficulty with intubation
2. Inability to tolerate supine position
3. Rapid desaturation, even with adequate preoxygenation due to reduced functional residual capacity
4. Increased susceptibility to anesthestics and opioid analgesics
5. Postoperative somnolence and apneic episodes
6. Increased risk of postextubation obstruction and negative pressure pulmonary edema[11]

Table 51-5

Recommendations for Perioperative Management of the Patient with OSA

1. Extubate when fully awake
2. Ensure full reversal of neuromuscular blockade prior to extubation
3. Extubation and recovery should be carried out in lateral, semiupright, or other nonsupine position
4. General anesthesia is preferable to deep sedation for superficial procedures
5. Oral or nasal airway or CPAP in nonnaïve patients during sedation
6. Consider postoperative respiratory compromise when selecting perioperative medications. In this regard, regional anesthesia, when compared with intravenous opioids, reduces the likelihood of adverse respiratory outcome

From American Society of Anesthesiologists. Practice guidelines for the perioperative management of patients with obstructive sleep apnea. A report by the ASA task force on perioperative management of patients with OSA. *Anesthesiology*. 2006;104(5):1081–1092 with permission.

Table 51-6

Additional Airway Management Strategies for the OSA Patient

1. Awake fiberoptic intubation
2. GlideScope
3. Creation of a ramp for head-up positioning
4. Thorough preoxygenation/denitrogenation
5. Availability of intubating LMA and other recommended devices for emergent airway management (as suggested by the ASA Difficult Airway Algorithm, 2003)
6. Properly sized oral and nasal airway placed prior to extubation

suspected OSA.[6] In addition, as noted, the OSA patient will more often present with difficult MV than other patients. The clinician should therefore be prepared to use adjunctive airway devices or emergent ventilation devices, such as the laryngeal mask airway. During spontaneous ventilation preoxygenation, the OSA patient may benefit from assistance with positive airway pressure provided by the anesthesiologist, or by his/her CPAP device,[13] as well as an upright position for preoxygenation and emergence. In 2006, the ASA developed practice guidelines[14] for the perioperative management of patients with OSA or presumptive OSA in the absence of a sleep study (Tables 51-5 and 51-6).

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CHAPTER

52 Morbid Obesity and Bariatric Surgery

Kevin M. Hibbard and Shawn T. Beaman

As the number of obese individuals in the United States continues to rise, the likelihood of encountering morbidly obese patients in the operating room, as well as the number of bariatric procedures, will predictably increase. Recent data has shown that 1 in 4 residents of the United States are classified as obese, which has increased approximately 24% since 2000.[1] The same study noted that individuals classified as morbidly obese, with a BMI over 50, showed the greatest percentage increase of prevalence between 2000 and 2005, rising more than 50%.[1] Data released in 2007 has shown that the number of bariatric procedures performed in the United States was expected to increase over 10-fold from 13,000 procedures in 1998 to 200,000 procedures in 2006, paralleling the significant rise in obese individuals.[2] Management of the airway of obese patients often presents challenges to the anesthesiologist while in the operating room. The increased difficulty, secondary to increased soft tissue on the patient's chest or in the airway, often complicates ventilation and/or laryngoscopy. In addition to the decreased chest wall and lung compliance that typically occurs during general anesthesia, many bariatric procedures are performed laparoscopically, which dictates the need for positive pressure ventilation via an endotracheal tube, with a further reduction in compliance. For these reasons, it is essential that all anesthesia providers become experts in the management of the airway in obese patients. In general, much of the difficulty in securing the airway of a morbidly obese patient involves management of the anatomic and physical challenges that are present secondary to the increased amount of adipose tissue and its related effects on the airway and lung volumes.

Although the exact definition is debatable, morbid obesity is commonly defined as a BMI greater than 40 kg per m^2. These patients typically manifest an increased amount of adipose tissue on their anterior chest, causing decreased chest wall and lung compliance. This results in a greatly reduced functional residual capacity (FRC), especially when the patient is placed in the supine position. Positioning a patient in the head-elevated position (ie, ear aligned with sternal notch) as opposed to the supine position results in a 23% increase in arterial oxygen tension and a 29% increase in time to desaturation after 3 minutes of preoxygenation.[3] These increases are thought to be a direct result of increased FRC and an increase of oxygen reserve during the apneic period prior to intubation.

In addition to an increased amount of adipose tissue on their anterior chest, morbidly obese patients have an increased amount of subcutaneous adipose tissue on their anterior and posterior neck leading to decreased anterior mobility of pharyngeal structures and to decreased neck extension during laryngoscopy, respectively. Lastly, it has been shown that there is an increased amount of submucosal tissue in the oral cavity and pharynx of obese patients. This increased tissue can result in an enlarged tongue, increased size of the tonsillar pillars, and encroachment of the posterior pharyngeal wall into the pharyngeal space with an increase in both Mallampati class and Cormack–Lehane grade view (see also Chapter 51).[4] The body habitus, as opposed to the absolute weight of the patient, is a more predictive factor in determining the difficulty with intubation and ventilation.[4] An android body habitus with more abdominal adipose tissue, as opposed to a gynecoid body habitus with more hip and buttock adipose tissue, will typically cause a greater decrease in lung compliance in the supine position secondary to increased pressure on the diaphragm during inspiration. This can lead to even less effective preoxygenation and increased airway pressures during ventilation after that patient has been intubated.

Recently, attention in the literature has focused on whether obese patients actually present an increased risk of difficult ventilation or intubation. A study by Juvin et al[5] in 2003 concluded that obese patients were more difficult to intubate as compared with nonobese patients. The authors reported an increase in multiple attempts at intubation and a decreased Cormack–Lehane grade with direct laryngoscopy of obese patients.[5] In contrast, the authors of a recent study found that, after intubating 100 morbidly obese patients presenting for bariatric surgery, there was no relation between patient weight and difficulty with intubation.[6] In this investigation, only Mallampati class and neck circumference were predictive of difficulty with intubation.[6] More recently, a study by Gonzalez et al,[7]

in which obese and nonobese patients were compared, found that obese patients were several times more likely to have an intubating difficulty score greater than 5 and were therefore classified as difficult to intubate. The authors further showed that a relationship exists between difficulty of intubation in an obese patient and an increased neck circumference, or a Mallampati class of 3 or greater (Fig. 52-1). The exact neck circumference that would be predictive of a difficult airway is not precisely defined, but it is estimated to be greater than 46 cm or 18 inches.[7] These studies suggest that morbid obesity does not, in and of itself, predispose a patient to having a difficult airway. However, physical characteristics that are more likely to be present in an obese patient, such as increased Mallampati class and increased neck circumference, will likely result in such a patient having an airway that is difficult to intubate.

Preparation is the most important step for managing any patient with a suspected difficult airway. This is especially true when providing care to the morbidly obese patient. A thorough and meticulous physical examination focused on the airway and respiratory systems should always be performed prior to transporting the patient to the operating room. The anesthesia provider should pay special attention to the patient's ability to tolerate the supine position as reflected by oxygen saturation and respiratory mechanics. When preparing for induction, the anesthesia provider should have various airway devices immediately available in case of difficulty with mask ventilation or direct laryngoscopy. A proper selection includes equipment necessary to intubate the trachea with fiberoptic bronchoscopy (see Chapter 23). Additional emergency equipment includes laryngeal mask airways of various sizes, an Eschmann stylet, specialized laryngoscope blades suited to handle increased pharyngeal soft tissue (such as a Bainton blade, Fig. 52-2), and the apparatus necessary for transtracheal jet ventilation. The presence of a second experienced airway provider is also prudent. Because difficult airways are often unpredictable, it is always appropriate to prepare for the worst possible outcome when managing the airway of the obese patient.

A key step in preparing to secure the airway of a morbidly obese patient involves proper patient positioning. For reasons described above, it is of the utmost importance to position the patient properly prior to induction, to provide both the best possible preoxygenation, and to optimize direct laryngoscopy. The goal in positioning the obese patient is to decrease the compression of the patient's thoracic cavity by anterior chest wall adipose tissue, while maintaining as much FRC as possible during preoxygenation and induction. The most beneficial positioning technique is an elevation of the chest and head, sometimes called the head-elevated laryngoscopic position or HELP. HELP increases the effectiveness of preoxygenation and prolongs the interval before oxygen desaturation occurs, the "desaturation safety period" described by Dixon et al.[3] In HELP, the patient's head, chest, and shoulders are elevated, with mild neck extension, thus improving alignment of the pharyngeal and laryngeal axes of the airway. Proper positioning aligns the patient's sternum and external auditory meatus along an imaginary horizontal line (Fig. 52-3).[6] The technique is usually performed by constructing a ramp of folded blankets on the operating room table prior to the patient transferring from the stretcher. This position also relieves excess weight on the patient's anterior neck during laryngoscopy and decreases pressure on anterior chest and neck caused by the weight of excessively large breasts (Figs. 52-4 and 52-5). With proper positioning, obese patients may be no more difficult to intubate than the average-sized patient.[7]

Several commercial devices and ramps have recently been developed to assist the anesthesiologist in positioning the obese patient in the head-elevated position. One product is a preformed foam ramp (Troop Elevation Pillow, C&R Enterprises, Frisco, TX, USA) designed to be placed directly onto the operating room table to elevate the head and shoulders of the patient while still providing neck extension (Fig. 52-6). The Troop elevation pillow can be positioned properly prior to and after induction with greater speed and ease when compared with folded blankets. It was also marketed as an alternative to the trial and error method needed to properly align the patient using blankets. An alternative that may be commercially available soon entails the use of an inflatable, multichambered pillow to properly position the patient (Fig. 52-7).[8] This pillow can be used to position the patient properly prior to induction, then deflated for the remainder of the surgical procedure, negating the need to roll the patient and remove blankets or a ramp prior to beginning the surgery. The device can subsequently be reinflated for optimal positioning prior to extubation.

Other methods for proper positioning of the obese patient involve the use of innovative operating room table adjustments prior to induction. The simplest technique involves a combination of the reverse Trendelenburg position and elevation of the patient's head. A second method is the Whelan–Callicott position, which calls for a 30° reverse Trendelenburg position with the headpiece extended, without any supports behind the patient's head. This permits proper alignment of the sternum and the external auditory meatus along a horizontal line.[9] A third alternative requires flexion of the operating room table at the trunk-thigh hinge, while providing a degree of neck extension using the head piece, with the goal once again to align the sternum with the external auditory meatus.[10]

Regardless of whether a morbidly obese patient is to undergo a bariatric procedure or any other type of procedure the same steps should be employed to secure the patient's airway. The most critical step involves using clinical judgment as to whether the patient's airway necessitates intubation using an awake fiberoptic approach. If a proper airway examination demonstrates that the patient



FIGURE 52-1 A supine morbidly obese female with a BMI of 46 kg/m^2, a Mallampati class three airway, and a neck circumference greater than 50 cm.



FIGURE 52-2 The Bainton laryngoscope blade, which has a tubular distal portion used to increase visualization of the glottis in patients with significantly increased pharyngeal soft tissue or pharyngeal edema that would normally obstruct the view of the airway. The Bainton blade can accept endotracheal tubes up to size 8.0 through the tubular portion with the adapter removed.



FIGURE 52-3 Obese male in the HELP position with the head and shoulders elevated by stacked folded operating room blankets. Notice the sternum and external auditory meatus are aligned along a horizontal line.



FIGURE 52-4 Obese female in the supine position with excessive anterior neck adipose tissue.



FIGURE 52-5 The same obese female at a later date in the HELP position prior to induction.

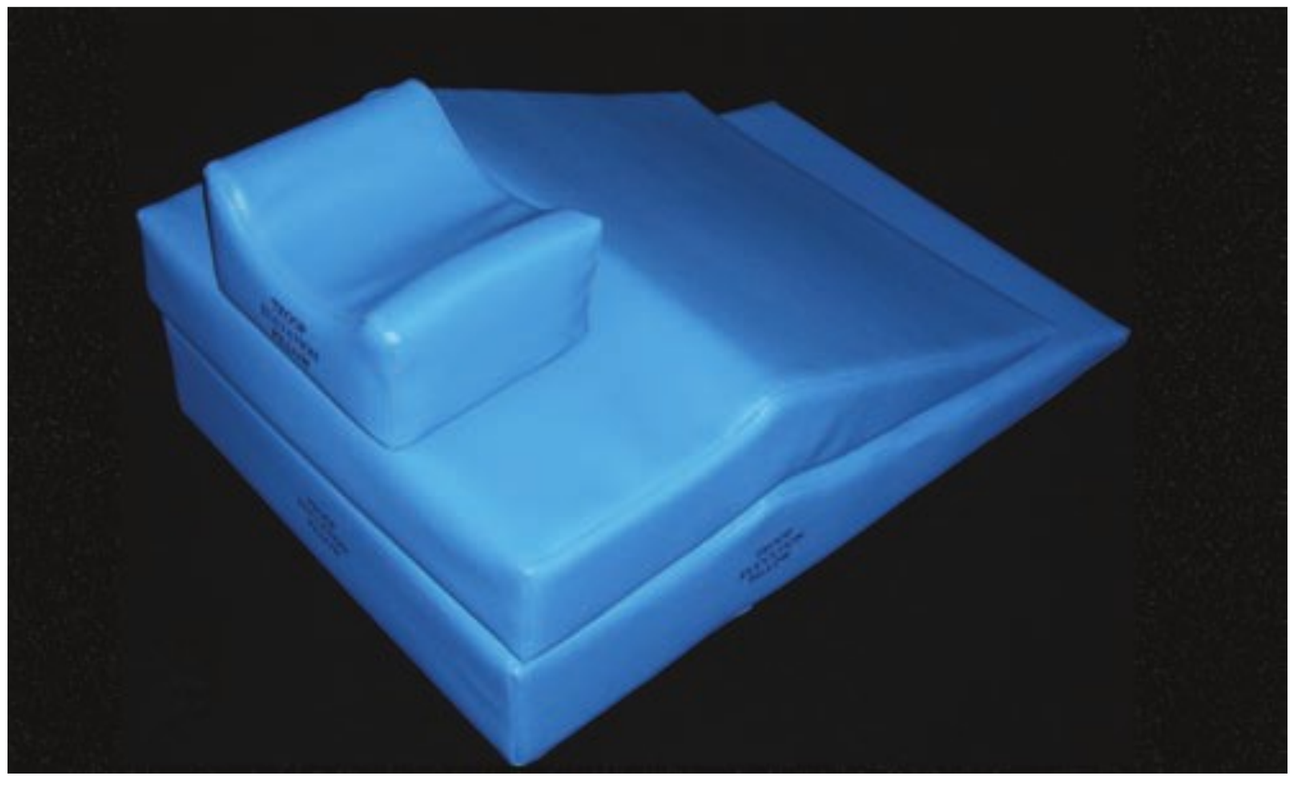


FIGURE 52-6 The Troop elevation pillow with normal operating room pillow resting on top.

(Reused with permission from Ogunnaike BO, Whitten CW. Anesthesia and obesity. In: Barash PG, Cullen BF, Stoelting RK, et al, eds. Clinical Anesthesia. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2009:1243.)



FIGURE 52-7 A multichambered inflation device used for positioning the patient in the HELP position. The ramp can be deflated and remain in place during the procedure instead of having to be removed prior to the operation. (Reused with permission from Ogunnaike BO, Whitten CW. Anesthesia and obesity. In: Barash PG, Cullen BF, Stoelting RK, et al, eds. Clinical Anesthesia. 6th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2009:1243.)

may be safely intubated by direct laryngoscopy, it is of great importance to have proper patient positioning prior to induction with the patient in the HELP position. Proper emergency airway equipment should be immediately available in the operating room. It is also advised that a second experienced anesthesia provider be present in the operating room during induction for assistance if needed. In the case of an unanticipated difficult airway, the American Society of Anesthesiologists Difficult Airway Algorithm should be followed using either invasive or noninvasive techniques to provide adequate ventilation or to intubate the patient.[11] With proper patient positioning, planning, and a thorough understanding of the influences of excessive adipose tissue on the anatomy of the obese patient, the anesthesia provider should be able to manage this group of patients safely and competently.

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CHAPTER 53

Obstetrics

Kristin M. Ondecko Ligda and Manuel C. Vallejo

INTRODUCTION

Airway management of parturient patients presents a challenge to the health care practitioner as two lives are being cared for at one time. Maternal complications such as failure to maintain an airway can contribute to fetal morbidity or even death.

In a review of the Centers for Disease Control and Prevention Pregnancy-Related Mortality Surveillance System, 2.5% of maternal deaths were attributed to anesthesia, and the most important cause (58%) of anesthesia-related maternal mortality was failure to maintain the airway.[1] Although there have been significant advancements in airway management technology such as the laryngeal mask airway and the GlideScope, and in the development of the American Society of Anesthesiologists (ASA) Difficult Airway Algorithm, the obstetric patient continues to be at risk of failed intubation when compared with the general population.

During an evaluation of anesthesia-related maternal mortality between 1979 and 1990, general anesthesia presented a greater risk of maternal mortality than regional anesthesia. Maternal death occurred most frequently during cesarean delivery (82% of deaths). Of these, 52% of deaths were the result of complications from general anesthesia, which were attributed to hypoxia, difficult or failed intubations, or pulmonary aspiration.[2]

PREGNANCY-RELATED ANATOMIC AND PHYSIOLOGIC CHANGES

There are several pregnancy-related changes to the parturient's anatomy and physiology that places her at increased risk for airway management difficulties (Fig. 53-1).

- Weight gain: the average parturient gains approximately 12 kg or 17% of her prepregnancy body weight as the result of an increase in the size of the uterus, placenta, and fetus; an increase in blood and interstitial fluid volumes; and an increase in fat deposition.[3] Increased body mass and obesity, in particular, increase the risk of the patient having a difficult airway and also the risk of emergency cesarean delivery.[4]
- Enlarged breast tissue: Enlarged breast tissue, especially in the supine parturient, can affect the practitioner's ability to manipulate the laryngoscope and obtain adequate laryngeal views and alignment of the laryngeal, pharyngeal, and mouth axes during intubation.[5]
- Airway edema: Contributors to airway edema include higher estrogen levels and increased blood volume. Comorbidities such as preeclampsia or respiratory infections may also contribute to airway edema. These all can lead to mucosal edema of the nares, tongue, oropharynx, and larynx, in addition to engorgement of the capillary beds with mucosal friability. Tongue enlargement may also hinder adequate placement of the laryngoscope blade into the mouth and larynx. Airway edema may make placement of the endotracheal tube challenging, if not impossible.[6–9] Hence, because of airway edema in the parturient, the best laryngoscopic intubation attempt is often the first attempt. Repeated attempts can often lead to further mucosal bleeding and subsequent intubation failure.
- Risk of aspiration: The obstetric patient, due to increased levels of progesterone, experiences decreased lower esophageal sphincter tone. The gravid uterus also contributes to increase in intragastric pressures and distorts the anatomy of the lower esophageal sphincter, diaphragm, esophagus, and stomach. These all can contribute to gastroesophageal reflux throughout pregnancy.[10–12] Additionally, advanced labor can contribute to delayed gastric emptying times. Although pain is thought to contribute to the delay, the delay in gastric emptying is still present even with an effective epidural anesthetic.[13]
- Risk of hypoxia: Pregnancy induces changes to respiratory mechanics and physiology. Pregnancy has not been shown to change the FEV1, FEV1/FVC, flow-volume loops or closing capacity; however, pregnancy is known to increase diaphragmatic excursion and decrease chest wall excursion. The gravid uterus displaces the diaphragm, which contributes to a decrease in residual volume. Tidal volumes increase early in pregnancy, and increase up to 45% from prepregnancy values, which leads to increased minute ventilation.[14] Oxygen consumption increases in pregnancy due to the increased metabolic requirements of the fetus and mother, alongside increases in carbon dioxide production, further contributing to the increase in minute



FIGURE 53-1 The parturient's increased weight gain, enlarged breast tissue, airway edema, risk of hypoxia, and risk of aspiration from the gravid uterus places her at increased risk for airway management difficulties. (Photo as originally included).

ventilation.[15] Starting in the second trimester, the gravid uterus displaces the diaphragm in the cephalad direction, which contributes to the decrease in the residual volume, expiratory reserve volume, and function residual capacity. The functional residual capacity (FRC)is decreased nearly 20% by term.[14–16] The FRC is further decreased in the supine position, along with decreased cardiac output secondary to aortocaval compression.[17] The reduced FRC can actually fall below closing capacity with resultant airway closure, leading to increased alveolar-arterial oxygen gradient. Obesity also contributes to decreased FRC. Therefore, because the parturient has an increased respiratory rate and lower FRC, the pregnant patient is at higher risk of hypoxia and apnea compared with the normal adult.

ASPIRATION RISKS

Maternal morbidity due to pulmonary aspiration of gastric contents has decreased in recent decades due to the use of neuraxial anesthesia; antacids, histamine-receptor antagonist, and/or proton pump inhibitors; rapid-sequence induction for general anesthesia; and establishment of *nil per os* (NPO) recommendations.[18] Avoidance of general anesthesia and usage of neuraxial anesthetic techniques are the most important contributors to the maternal mortality decline.

However, risk factors still exist for aspiration pneumonitis that are based on the composition of the aspirate (nonparticulate or liquid vs particulate), the pH of the fluid (pH less than 2.5 associated with higher risk), and its volume (greater than 25 mL or 0. 4 mL/kg associated with higher risk).[19] In addition to a decrease in lower esophageal sphincter tone, difficult or failed intubation is also associated with an aspiration risk in the peripartum-period.[20] Interestingly, the risk of aspiration is also present upon extubation, just as upon intubation, and thus, prophylactic measures should also cover the time frame of emergence in addition to induction.

Those parturients who are scheduled for elective cesarean section should fast from solid and liquid foods according to ASA guidelines. In addition, preoperative prophylactic measures given prior to induction of anesthesia to minimize the risk of aspiration include an oral nonparticulate antacid, histamine (H2)-receptor antagonist, proton pump inhibitors, and/or metoclopramide.[21] In emergency cesarean deliveries, oral nonparticulate antacid should be given when the patient is transferred

to the operating room, and if possible, the patient may be given intravenous H2-receptor antagonist or proton pump inhibitor. For a woman in labor, studies have shown that liberalized NPO policies, such as allowing water only or eating during labor, did not improve obstetric outcomes but did increase gastric residual volumes and volume of vomitus.[22]

Cricoid pressure, or the Sellickmaneuver, can also be applied to minimize the aspiration risk during induction of general anesthesia. The goal is to apply pressure via the cricoids, the only solid ring in the larynx, on the esophagus to prevent stomach content regurgitation. Cricoid pressure is maintained until there is confirmation of the placement of the endotracheal tube in the trachea and the endotracheal tube cuff is inflated.

To minimize the risk of aspiration, general anesthesia in the parturient should be reserved for those who are unable to receive a neuraxial anesthetic, such as patients with elevated intracranial pressures or coagulopathies, or for emergent cesarean deliveries (as in the case of uterine rupture or severe fetal distress) for which aneuraxial anesthetic cannot be placed.

DIFFICULT AIRWAY

The increased BMI combined with the pregnancy-related changes to the airway place the parturient at increased risk of difficult intubation. In the general population for surgery, the rate of failed intubations is approximately 1 in 2,330; however, the incidence is nearly eight times more prevalent in the obstetric patient, occurring in 1 in 283 obstetric patients,[23] despite advances in airway devices and educational resources for practitioners such as the ASA Difficult Airway Algorithm. Although morbidity from failed intubations has also occurred, the mortality from failed intubation was estimated to be 13 times higher in the obstetric population than the general population for surgery.[24]

Prediction of the difficult parturient airway would include the standard patient assessment including Mallampati classification, thyromental distance, head extension, mandibular protrusion, and identification of cricothyroid membrane. In addition to the anatomic and physiologic changes particular to the parturient, other characteristics of possible difficult airways include full dentition, small mandible, limited mouth opening, limited neck flexion or extension, short or thick neck, arched palate, and protruding incisors. Other comorbidities, such as rheumatoid arthritis or Arnold-Chiari malformations, may also contribute to airway difficulties.[25]

In select high-risk parturients, placement of a prophylactic epidural catheter may be used to provide neuraxial anesthesia should an emergent cesarean delivery be necessary (Fig. 53-2). The epidural catheter could then be activated when the active stage of labor is reached. As with any patient with an expected difficult airway, an awake intubation should be performed to secure the airway. In addition, the same vigilance for the airway should be maintained during extubation as during intubation.

In an unexpected difficult airway, use of the ASA's Difficult Airway Algorithm is important while maintaining maternal and fetal oxygenation. When the patient is unable to be ventilated by mask, the laryngeal mask airway is the first line rescue device with needle cricothyrotomy with transtracheal jet ventilation as an alternative.

Airway Management in Preparation for General Anesthesia:

- Proper preparation of the operating room, including availability of laryngoscope blades, extra endotracheal tubes, and suction is necessary. Ensure appropriate assessment of the patient, including airway examination, to recognize potential difficult airways.
- Formulate plan for induction, intubation, maintenance of anesthesia, emergence, and extubation with an alternative plan in mind for each step.



FIGURE 53-2 The modern emphasis on regional anesthesia for labor and delivery, as well as operative delivery, has led to significant declines in maternal and fetal morbidity and mortality related to airway management. (Photo from Dr. Vallejo showing epidural placement.)

- Prior to induction of general anesthesia, aspiration prophylaxis with nonparticulate antacid should be administered to patients at high risk (ie, morbid obesity, known difficult airway, and diabetes with gastroparesis); histamine (H2)-receptor antagonist, proton pump inhibitors, and/or metoclopramide may also be provided.
- The gravid uterus of the supine patient contributes to aortocaval compression, reducing blood flow to the heart and cardiac output. A wedge, either preformed or one made from blankets, should be placed under the right hip to facilitate the displacement of the uterus 30°, which reduces the compression of the great vessels and improves uterine blood flow, as well as venous return to the heart.
- Due to the decreased FRC, increased oxygen consumption, and decreased cardiac output, effective denitrogenation and preoxygenation are essential in the parturient.
- Optimum positioning of the patient during preparation maximizes successful laryngoscopy of the larynx and intubation of the trachea. Methods to improve visualization during laryngoscopy include the following:
  - Semi-upright positioning by raising the shoulders, neck, and head off the bed to align the ear with the sternal notch to maximize alignment of the pharyngeal, laryngeal, and oral axes
  - Using either a short-handled laryngoscope or a pediatric laryngoscope handle with an adult blade
  - Positioning the breast tissue caudal and lateral by taping the tissue or manual displacement from the airway field.
- Prepare for rapid sequence induction of anesthesia with cricoid pressure applied until endotracheal tube cuff inflation and confirmation of tube placement within the trachea.
- Maintain vigilance during extubation as the same risks of airway edema, aspiration, and hypoxia exist during extubation as were present during intubation. Consider the use of an airway exchange catheter to maintain a conduit to the trachea.

CONCLUSION

The pregnant patient presents a challenge to the health care practitioner. A thorough discussion and establishment of a plan with the obstetrician should be held for each parturient. The principles outlined above will help to reduce morbidity to both the mother and the fetus related to airway management.

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PART XVI

Care After Intubation

CHAPTER 54

Positive Pressure Ventilation

Max Rohrbaugh and A. Murat

INTRODUCTION

As a guide to airway management, this book has so far focused mainly on establishing a secure channel between the trachea or main bronchi and the outside world, usually in the form of an endotracheal tube. This is a worthy goal and a prerequisite for life for most people, but it remains a means to an end. After the tube is in place, we must do something useful with it, namely, ventilate and oxygenate the patient. This chapter will introduce readers to positive pressure ventilation (PPV) by discussing basic concepts and definitions in respiratory physiology and universal themes in ventilator design. As we look at each of several classic modes of ventilation, we will suggest typical applications, guidelines for initial setup, and discuss the peculiarities of each mode. Finally we will briefly summarize some of the more recently developed approaches to mechanical ventilation in difficult to ventilate or oxygenate patients.

SPIROMETRY

Ventilation is simply mass movement of gas in and out of the lungs, or breathing. Regardless of whether an individual is breathing spontaneously or with artificial PPV, the volumes of gas moving in and out of the lungs can be measured in a process called spirometry. When these measured volumes are added up, we refer to the resulting sums as lung capacities.

Figure 54-1 shows a graph of volume versus time for respiration, which begins as normal relaxed breathing or tidal breathing. The volume moving in and out with each normal breath is called tidal volume (V_T). At time "a" on this graph, the person has inspired (breathed in) as much as possible and then at time "b" he has gone on to expire (breathe out) as much as possible. Inspiratory reserve volume (IRV) and expiratory reserve volume (ERV) are the maximum inspiratory and expiratory volumes, respectively, that can be attained beyond tidal ventilation. Residual volume (RV) is the volume remaining in the lungs that cannot be forcibly expelled during active expiration. The total volume that remains in the lungs after relaxed tidal expiration is the sum of ERV and RV and is called functional residual capacity (FRC). The total volume that can be inspired from that point is the sum of V_T and IRV and is called inspiratory capacity (IC). The total volume that a person can move in and out of the lungs at maximum effort is the sum of ERV, V_T, and IRV and is called vital capacity (VC). The total volume within the lungs at maximum inspiration is the sum of all the lung volumes, and we call it total lung capacity (TLC).

SCIENTIFIC UNDERPINNINGS OF PPV

Like all moving fluids, the gases that we breathe are pushed from a region of high pressure toward a region of lower pressure. In the case of spontaneous breathing, the diaphragm and other respiratory muscles work together to expand the thorax and create negative intrathoracic pressure relative to the outside atmosphere (note that throughout this chapter and in most of physiology, pressure will be measured relative to atmospheric pressure and atmospheric pressure is considered to be zero). In the case of most artificial ventilation, we apply positive pressure at the upper airway or within the trachea, and gas moves toward the region of relatively lower pressure within the lungs. In both situations, expiration is mainly passive. It is driven by lung elasticity pulling the intrathoracic volume down and increasing intrathoracic pressure until, at the point of full exhalation during tidal breathing (FRC), the inward force of lung elasticity is equal in magnitude and opposite in direction to the outward recoil of the relaxed inspiratory muscles and other tissues of the chest wall. Additional active expiration may be accomplished by contraction of the internal intercostal muscles and the muscles of the abdominal wall.

Before we delve into the specific topic of mechanical PPV, it is worth mentioning that there are other ways to provide artificial ventilation. First, there is the largely

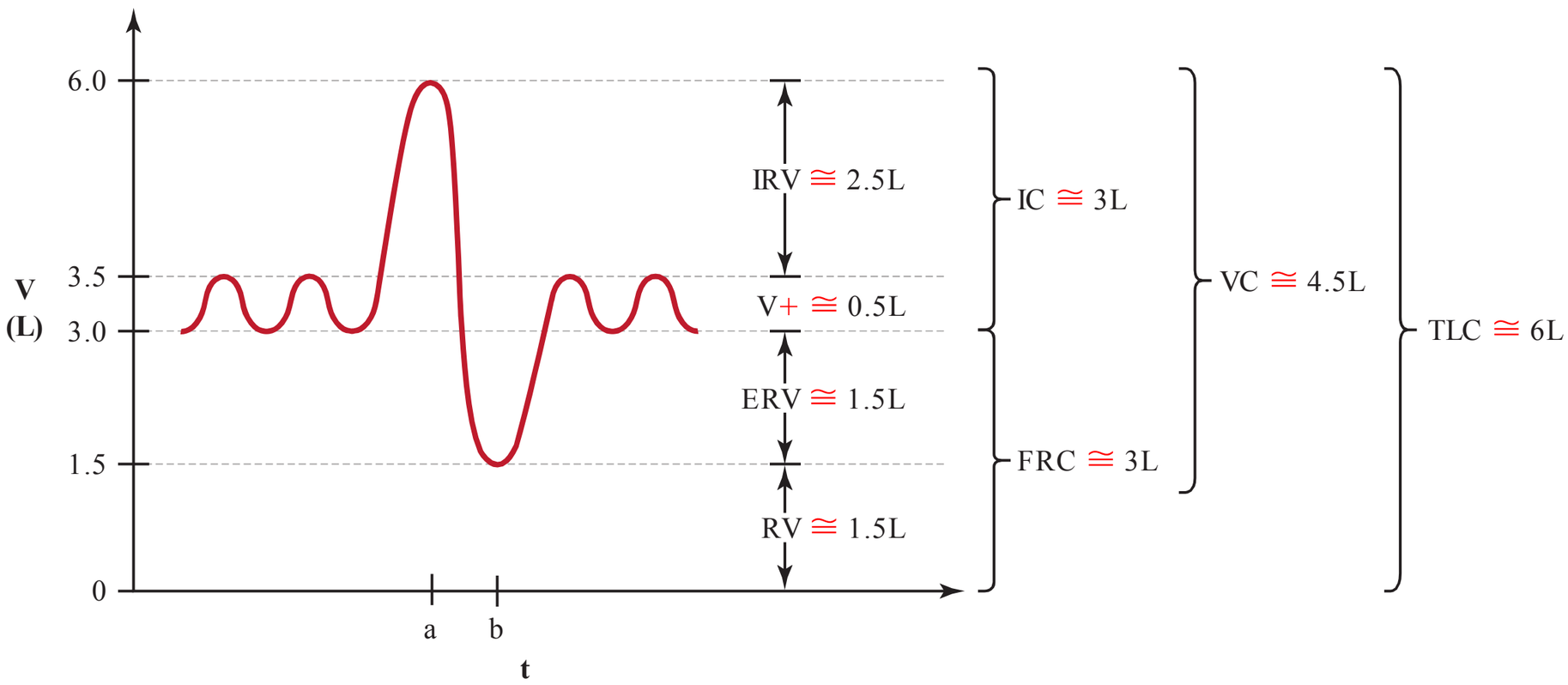


FIGURE 54-1 Graphic representation of lung volumes and capacities in an average adult.

historical example of negative pressure mechanical ventilation such as that provided by the iron lung. This device surrounded the patient's thorax while a seal excluded the neck and head. As the bellows, or, later, a separate compressor, generated negative pressure in the tube around the thorax, the chest wall transmitted it to the lungs and air flowed into that low-pressure region, generally by way of the natural airway. It served many patients with neuromuscular respiratory failure for decades of their lives, but it is difficult to move about to say the least, and even difficult to provide nursing care when the patient's body must be encased by the ventilator, so it has now largely been replaced by PPV, even for patients with very long-term ventilator dependence.

The other frequent exception to the model of mechanical PPV is that of manual PPV as provided by anesthesia and critical care practitioners daily by means of a gas-filled bag attached to a one-way valve. Providing manual breaths via natural or artificial airway is a lifesaving skill and can lead to a more intuitive understanding of the principles of PPV. Nonetheless, even the most seasoned anesthetist will fatigue at some point, so most of us will enjoy the luxury of being able to replace the work of our hands and forearms with a machine that is expressly made to ventilate lungs. This brings us to the remainder of the chapter, which will explain principles and practice of mechanical PPV.

Any reader who is not a respiratory therapist will likely recall his or her first introduction to mechanical ventilation as an alphabet soup of acronyms and confusing definitions. Unfortunately, naming and availability of modes of ventilation is inconsistent between different ventilator manufacturers. Furthermore, with the advent of computer-controlled ventilators, the subtle variations in modes of ventilation have become potentially limitless. For this reason, it is worthwhile to pause and build a strong theoretical framework for how we describe ventilator function and control. Unlike marketing pitches, the principles that govern the flow of gas in and out of human lungs are fairly simple and immutable. Fundamentally, any mechanical ventilator is a machine that uses a pneumatic or electric power source to take over a patient's work of breathing. Naturally, this must occur in a carefully controlled fashion in which some relevant variables related to respiration can be measured and input into the ventilator control system, which will process them and modify ventilator output accordingly. If the reader can understand all the possible ways that someone might design a machine to interpret and interact with these laws of fluids and respiratory mechanics, it should be easy to adapt to small modifications in the currently existing technology as they come about.

Regarding the power source, most modern ventilators use some combination of electrical and pneumatic power. Since stored medical gas in hospitals is already pressurized to approximately 50 psi, and gas stored in smaller tanks is at much higher pressure, it is efficient to use some of the energy that is released in the process of expanding stored gas to drive a bellows. Alternatively, some devices simply use regulator valves that only decrease the pressure down as far as the desired airway pressure mandates. On the other hand, the power source for a transport ventilator or the backup power source for a stationary ventilator is typically an electric compressor. Similarly, the control system for a simple ventilator can be purely mechanical and pneumatic as is the case for many of the simple intermittent positive pressure breathing devices that are used to administer inhaled medications. Modern ventilators, however, almost exclusively use electricity for their control systems: alternating current circuits for the small motors and direct current circuits for the computer systems and sensors.

The desired output of a mechanical ventilator is obviously ventilation. More specifically, appropriate ventilation must provide adequate minute ventilation.

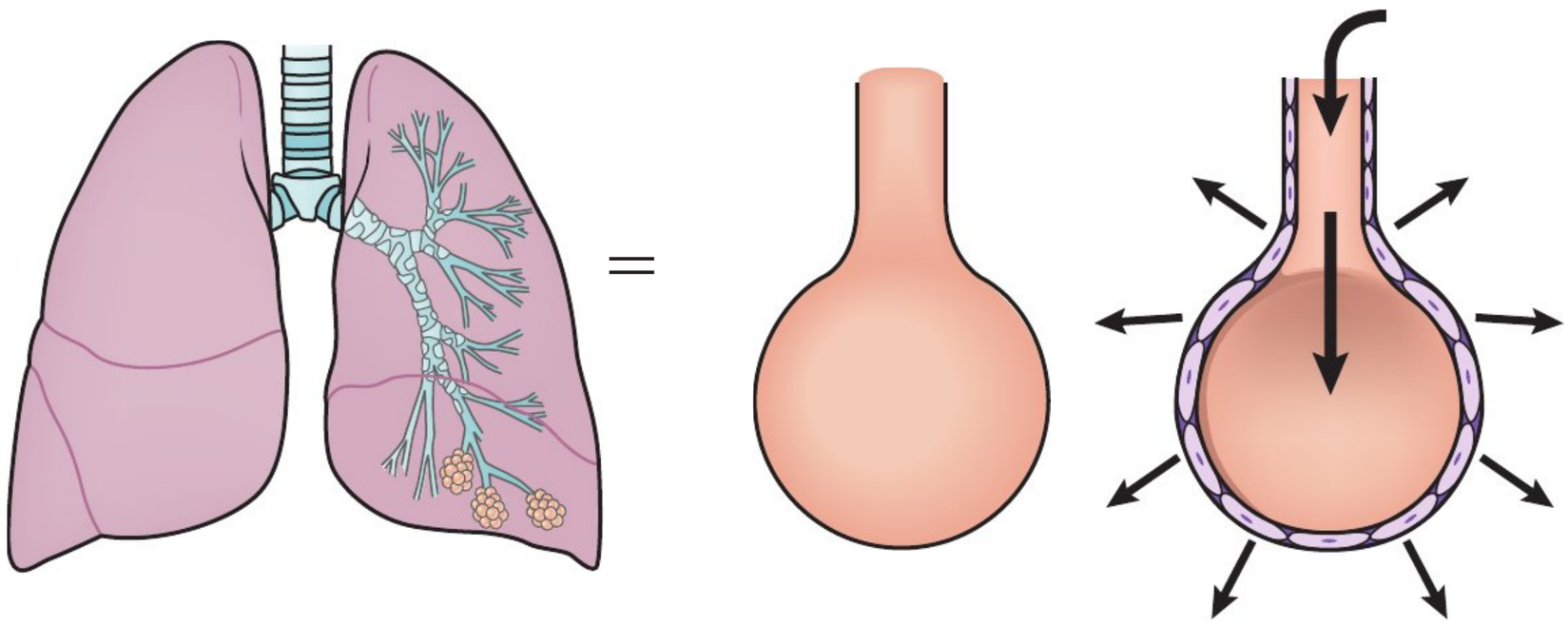


FIGURE 54-2 Single alveolus model for respiratory mechanics.

Appropriate ventilation can minimize both dead space ventilation (the amount of ventilation that does not participate in gas exchange because it is only in poorly perfused parts of the lung or airway) and shunt (blood that cannot participate in gas exchange because it flows through parts of the pulmonary circulation that are not well ventilated). For any patient there is an ideal balance point. We must provide large enough V_T so that all perfused portions of lung get ventilated and V_T is much larger than the wasted anatomic dead space ventilation, but we must avoid applying so much pressure to the lungs that it impedes pulmonary blood flow and increases physiologic dead space. In addition, excessive positive airway pressure can be harmful to the tissue of the lungs and reduce cardiac output, so the goals of ventilation must be balanced against the desire to limit peak airway pressure. The ideal rate of gas flow into or out of the lungs can also vary between individuals based on traits such as level of sedation, respiratory drive, body habitus, or specific lung or airway disease states.

The three main variables of PPV, namely volume, pressure, and flow, can be related to one another using a simplified model of respiratory mechanics. In this model, we will imagine all of the airways, bronchi, and bronchioles being represented as a single tube leading to a balloon that represents all of the combined alveoli (Fig. 54-2).

Using this single alveolus model, we can see that during a positive pressure breath, the inspired gas would be driven into the alveolus from a region of high pressure at the proximal airways toward a region of lower pressure in the alveolus, but we can also imagine that this movement would be opposed by the dynamic resistance to the flow of gas through the tube. The relationship between pressure, flow, and resistance is described by the following equations.

$$\text{Flow} = \text{Pressure} / \text{Resistance}$$

or, rearranged

$$\text{Pressure} = \text{Flow} \times \text{Resistance}$$

This relationship is dynamic because it involves a rate, and it only applies when there is gas flow through the tube. If there is no flow, then resistance is irrelevant, and the pressure that we measure at the airway cannot be influenced by it. Looking back at our balloon-on-a-straw however, we can also easily understand that there is a second, static force that opposes filling the balloon, and that is the elastic properties of the expanding balloon itself. The pressure that the balloon will exert back on the gas within it is governed by its elastance and volume according to the following equations:

$$\text{Elastance} = \text{Pressure} / \text{Volume}$$

or, rearranged

$$\text{Pressure} = \text{Elastance} \times \text{Volume}$$

If pressure at the mouth of the tube is set at a given amount and ample inspiratory time is allowed, elastance will determine what volume enters the balloon. When the volume is reached at which back pressure from the elastance of the balloon equals airway pressure, flow will stop. Then if the positive airway pressure is reduced or removed, the direction of the flow will be reversed until the pressure in the balloon is again equal to airway or ambient pressure. Note that we often discuss elasticity in terms of its inverse, compliance, which is simply change in volume over change in pressure.

Combining the static and dynamic components of the work of breathing additively, we arrive at a simplified equation of motion for the respiratory system.

$$\text{Total Pressure} = \text{Pressure from resistance} + \text{Pressure from elastance}$$

or

$$\text{Total Pressure} = \text{Flow} \times \text{Resistance} + \text{Elastance} \times \text{Volume}$$

This equation of motion allows us to relate all of the key variables of respiratory mechanics. Each of the variables can be manipulated in one way or another. Resistance and elastance are generally characteristics of the patient, whereas pressure, flow, and volume are each variables that that may be set by the ventilator.

Resistance to flow of an ideal fluid is described by Poiseuille's Law.

$$\text{Resistance} = (8 \times \text{viscosity} \times \text{length}) / (\text{pi} \times \text{radius}^4)$$

The natural airways are difficult or impossible to describe this way because they taper and branch and the flow in most of the airways is turbulent, but Poiseuille's Law is still a worthwhile model to keep in mind. It forms the theoretical basis for using a shorter, larger radius endotracheal tube or giving bronchodilator medications to reduce the resistance to airflow, or even the practice of mixing helium into the inspired gases for patients with severe airway obstruction in the hope of reducing resistance by reducing fluid viscosity of the inspired gas itself.

Like resistance, elastance in a living human is more complex than our single alveolus model would suggest. Rather than a single balloon, the intrinsic lung elastance is a function of several hundred million alveoli and the tissue that forms them, as well as the airways themselves. The elastance of real lungs is not constant either. Rather, it increases with increasing lung volume (Fig. 54-3).

In healthy people with normal lung tissue, a more significant component of elastance is often related to extrinsic sources. These include the pressure of an obese or insufflated abdomen pressing up against the diaphragm, variations in patient position such as Trendelenburg or prone positioning, or forces from the tissues of the walls of the thorax including active movements of the respiratory muscles, which may aid or oppose the ventilator. These factors are all important to consider, and they can be modified by a human clinician, but they are essentially constants from the perspective of the ventilator control algorithm. In contrast, the flow, volume, and pressure components of the equation of motion form the heart of ventilator management.

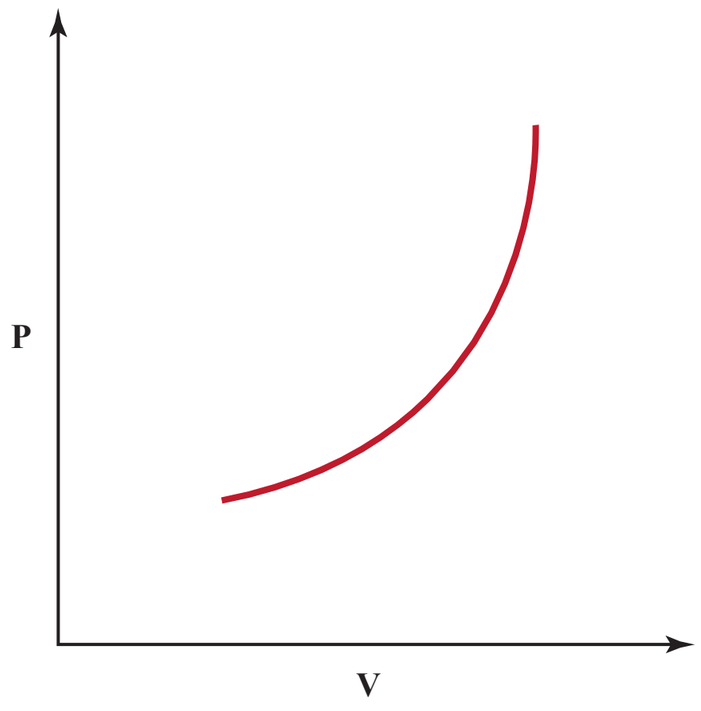


FIGURE 54-3 Pressure versus volume for inspiration (slope of a tangent is equal to compliance).

PRINCIPLES OF VENTILATOR CONTROL

As mentioned above, there are a plethora of specific modes of mechanical ventilation, and we will only discuss a few of the classics here. Before we proceed with this discussion, though, it will be valuable to consider the ways a ventilator could be controlled in theory, because most of these approaches are indeed being used by one device or another.

First, what can a ventilator know? That is to say, what variables are commonly input into a control algorithm? For a start, a ventilator must monitor the three essential parameters that will determine the mass movement of gas as discussed above: pressure, flow, and volume. Like so many other things, the exact location of these sensors (eg, inspiratory arm, expiratory arm, T-piece next to endotracheal tube itself) and subsequent way that the data is used varies between manufacturers. As a curiosity, it is also notable that flow is the derivative of volume with respect to time, and, inversely, volume is the integral (or area under the curve) of flow over a period of time, so many ventilators measure one of these two variables and calculate the other. If the ventilator does not have a bellows or piston, most likely it is actually measuring flow and integrating it to produce the values of volume that show up on its settings or display screen. We will intentionally perseverate on pressure, flow, and volume, but perhaps the most fundamental variable that the ventilator keeps track of is time. Almost any other variable for which an electronic sensor has been invented is fair game for the ventilator to monitor and respond to, and there are a few notable examples. Many modern anesthesia ventilators integrate the concentrations of several inspired and expired gases into their displays, and even many intensive care ventilators measure and display or trigger alarms based on inspired O_2 and expired CO_2 levels. It is also possible to use pressure sensors outside of the ventilator circuit or even electrodes on the chest that measure impedance to estimate chest volume. Indeed, both of these techniques are used clinically to trigger the inspiratory phase in some infant ventilators. Of course, ventilators must also be able to act on human operator inputs and most of their functions can be triggered manually by a clinician. As any of these variables are measured and input into the ventilator control system, they can be used for different purposes, and we will categorize them further based on what the control algorithm does with them.

A control variable is simply the parameter that the ventilator controls during inspiration. Its magnitude could

be constant, but just as often it varies over the inspiratory time as is demonstrated by the many waveforms in Fig. 54-4. Note, for instance, that the first pressure control waveform applies constant pressure, but the second uses an ascending ramp waveform for pressure. Both of these examples are still using pressure as the control variable though. In mathematical terms, the control variable is the *independent variable* in the equation of motion, and at any given time, the other two ventilator-specific variables *depend* on the interplay of the control variable with the patient-specific properties of elastance and resistance. For example, if we set a particular pressure waveform as the control variable, then V_T and flow rates will result based on the resistance and elastance of the system. They are directly related to each other, and if the pressure is increased, higher volume and flow will result, whereas if the pressure is set lower, there will be a decrease in the volume and flow delivered. On the other hand, if a mode of ventilation that specifies volume or flow for the control variable is chosen, then we cannot have direct control over the pressure that is generated to reach that target, but we still know that the variables will be directly proportional to one another. As noted previously, volume and flow are closely related, with flow being the derivative of volume with respect to time, so for clinical purposes when we control one of these two variables over a set period of time, we are, in essence, controlling the other.

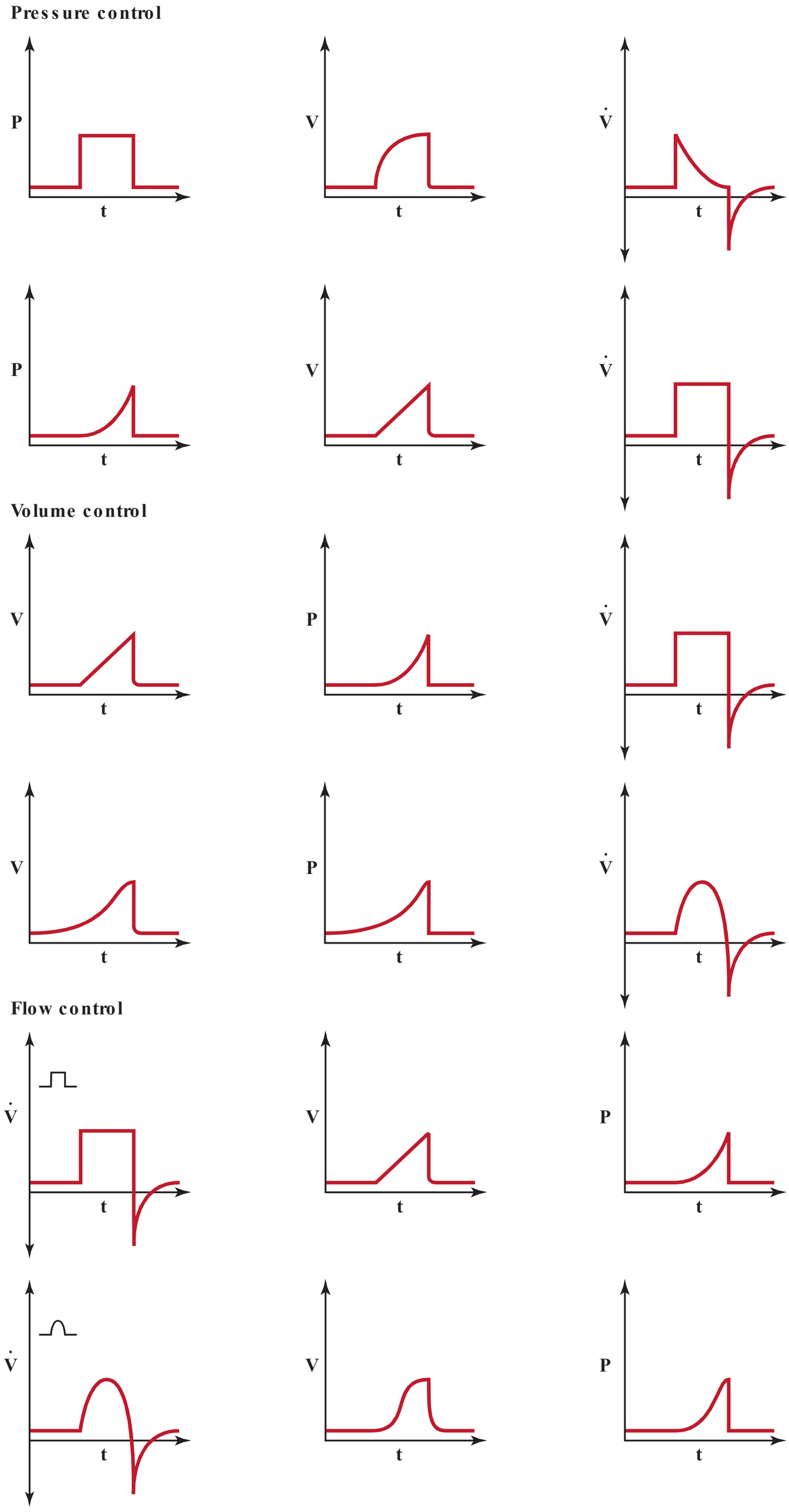
With regard to time, our simplified equation of motion explains some important relationships, but it does not tell us much about how they change over the time of a respiratory cycle. First, recall that elastance increases with increased lung volume, so during inspiration, elastance increases with time also. In contrast, resistance is usually higher at lower lung volumes, but the magnitude of that change is smaller over a typical respiratory cycle, so we can usually ignore it. The remaining relationships will always be consistent with the equation of motion, but we can set various waveforms for the control variable. Some common control waveforms and typical resulting waveforms of the dependent variables are shown in Fig. 54-4.

PHASE VARIABLES

A phase variable is a variable that directs a ventilator to initiate, sustain, or terminate inspiration, or to maintain some type of baseline characteristic during the time designated for passive expiration. More specifically, there are four names for these subtypes of phase variables. A baseline variable is a variable that is controlled during expiration, and the most common example would be positive end expiratory pressure (PEEP). The variable that causes the ventilator to initiate inspiration is called a trigger variable. Some common trigger variables are time (the ventilator gives a breath at a set frequency), pressure (the ventilator gives a breath when the patient generates a small negative pressure), flow (the ventilator gives a breath when the patient creates a small inspiratory flow), and simply a manual breath in which an operator triggers the inspiratory phase by pushing a button on the ventilator control panel. The inspiratory phase is ended by a cycle variable. Common examples include time (continue inspiration for a preset time period and then cycle to expiration), pressure (terminate the inspiratory phase when a high pressure is reached), volume (permit expiration as soon as the breath reaches a set volume), or flow (cycle from inspiration to expiration when the inward flow of gas drops below a certain rate). Finally, if one of the variables related to respiration is limited at a certain level during the inspiratory phase it is called a limit variable. This can be a confusing concept, but it may help to consider the real world example of how we could keep a ventilator from applying too much positive airway pressure to a patient during a volume controlled breath. Anyone who has spent a few hours in an intensive care unit (ICU) will have some frame of reference for this because most of the ventilator alarms that we hear echoing down the hallways are the result of a high-pressure alarm going off. The way that a ventilator is set to respond to that high-pressure event illustrates the difference between a limit variable and a cycle variable. If we set an upper level of pressure that we will tolerate as a true *limit variable*, then when that level is reached during an attempt at inspiration, the inspiratory phase will continue—but at the cost of a reduced flow, longer inspiratory time, or failure to reach the targeted volume. In contrast, if a set pressure "limit" is exceeded and the ventilator responds to the event by terminating the inspiration, then this high-pressure value is not really being used as a limit variable by the ventilator, rather it is a *cycle variable*. In fact, the latter is the more typical action that a ventilator takes when the high-pressure "limit" is reached. Note that the first situation is an example of a dual control mode because the inspiratory phase is initiated with volume being the control variable, but after a high-pressure limit is reached, it switches to a pressure controlled breath for the remainder of that inspiratory cycle (Fig. 54-5).

At this point we have described in theoretical terms most of the fundamental inputs and outputs that let a ventilator "know" how to deliver a positive pressure breath to a patient, but as was described above, modern ventilators are equipped with fairly sophisticated computers and can take on many tasks beyond controlling a single inspiratory cycle. Between breaths and over longer periods of time, most ventilators are busy processing larger conditional statements to determine that each breath is cycled based on the correct set of control and phase variables. Ventilators can even use feedback from prior breaths to change the way future breaths will be delivered. At the extreme end, a few ventilators can use information about past respiratory rate and V_T to provide a minimum level of assistance to the patient and automatically wean through decreasing levels of ventilatory support. More typically,

FIGURE 54-4 Common pressure, volume, and flow control waveforms.



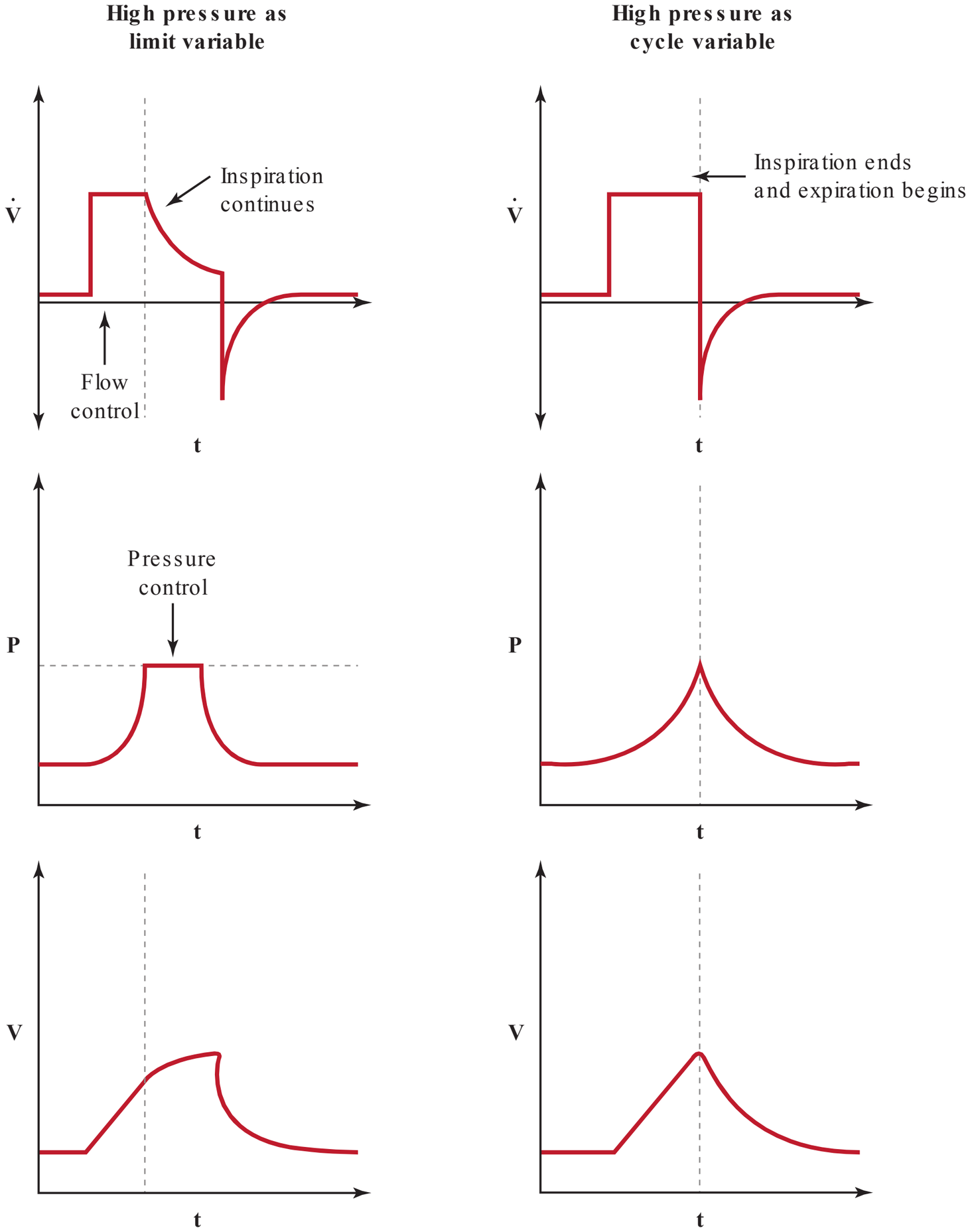


FIGURE 54-5 Flow, pressure, and volume versus time for a high-pressure alarm acting as limit variable (left) compared with high-pressure alarm acting as cycle variable (right).

most of our key alarms rely on integration of spirometric or other data over successive breaths, and the ventilator will sound an alarm and may switch to a more supportive mode of ventilation or to a backup system if variables such as expiratory time, minute ventilation, inspired oxygen concentration, input power, pressure, or others fall outside of a predetermined range.

The last necessary component of ventilator mode classification is often called "breath type" and refers to the source of the phase variables—that is, does the patient or ventilator produce the changes that will trigger or cycle the breath? There are four types of breaths in this respect. First, if a breath is triggered and cycled based on the actions of the patient, it is a spontaneous breath. Some authors make a further distinction, subdividing this category into the completely spontaneous breath and the supported breath. In this scheme, a truly spontaneous breath is one in which the ventilator does not change any of its output variables in the inspiratory phase compared with the expiratory phase. In contrast, during the supported breath, the ventilator provides higher airway pressures during an inspiratory phase, but the breath is triggered and cycled based on changes that the patient evokes. An assisted breath is triggered by some action by the patient, but after that, all of the limit and cycle variables are determined by the ventilator independent of any input from the patient. Finally, a mandatory breath is one in which the trigger, limit, and cycle variables are all based on the ventilator's work, without any input from the patient. These breath types are a key way that we classify modes of ventilation. A brief but useful classification of any mode of ventilation can be made by identifying the predominant breath type that it offers (often stipulating whether this breath type is continuous or intermittent) and identifying the control variable. Mentioning any peculiar phase or conditional variables provides the ultimate level of detail.

We are finally ready to look at common specific modes of ventilation.

MODES OF VENTILATION

We will now look at several essential modes of positive pressure mechanical ventilation and describe them in terms of breath type, control variable, and phase variables.

Continuous Mandatory Ventilation

Continuous mandatory ventilation (CMV) is a mode of ventilation in which every breath is mandatory, that is, machine triggered and machine cycled. In its broadest form it can be either volume controlled or pressure controlled, and, for clarity, it should be referred to as VC-CMV or PC-CMV, respectively (although we know that, to be more precise, modes called volume control are often performing flow control over a set time period). Many clinicians and ventilator menus refer to these as simply VC or PC using the somewhat confusing convention of calling a mandatory breath a "controlled breath" (we will not use this terminology further here). The trigger variable will usually be time, but the limit variable can be pressure, volume, or flow, and the cycle variable could be pressure, volume, flow, or time. Because it is a fully mandatory mode with no useful or synchronized way to respond to patient interaction, CMV is best suited to deeply sedated or paralyzed patients.

Assist/Control

Assist/control (A/C) is a mode of ventilation in which mandatory breaths must occur at a set minimum frequency, so its fully mandatory breaths are time-triggered. Above that minimum rate, however, it will also sense patient effort (either in the form of a small negative pressure or a small inward flow) to trigger a breath. After the patient triggers the breath, the limit and cycle variables will be reliant on the ventilator's actions and generally are the same as those of the mandatory breaths. By definition then, these extra breaths are assisted. Aside from the different source of the trigger for assisted and controlled breaths, the control, limit, cycle, and baseline variables for the assisted and controlled breaths are usually identical. Just as we saw with the term "CMV," calling the mode "A/C" communicates the breath types that are available, but to be clear, we would then need to further stipulate whether it is pressure control A/C or volume control A/C. In practical terms, this could be inferred from the ventilator orders because in addition to writing A/C, we will either order a desired pressure or a desired volume.

Within the boundaries of the definition above, it is interesting to consider different ways that A/C can be manipulated to be more like or unlike CMV. For instance, if the set minute ventilation is higher than necessary for the patient's metabolic demands, the patient is thoroughly sedated or paralyzed, or for any other reason the patient does not initiate any inspiration between the mandatory breaths, then the ventilator output will be identical to CMV, with only mandatory breaths occurring. Likewise, if the threshold for the patient to trigger an assisted breath is set very high (meaning the patient must generate an unattainably large negative pressure or high inward flow to trigger a breath) then the mode really will function just like CMV in every practical way. In contrast, if the mandatory rate is set at zero, then every breath will have to be triggered by the patient. Some ventilators separate this assist-only mode as a separate menu option called Assisted Mechanical Ventilation (AMV), or simply Pressure Assist or Volume Assist, depending on the control variable.

Intermittent Mandatory Ventilation

Although there are inconsistencies between manufacturers, in general, intermittent mandatory ventilation (IMV) is a mode of ventilation in which fully mandatory breaths are given at a set rate (time triggered with machine-based limits and cycle variables), but between those mandatory breaths the patient is permitted to take either fully spontaneous (similar to continuous positive airway pressure (CPAP) as described below) or supported breaths (similar to pressure support ventilation (PSV) as described below).

Synchronized Intermittent Mandatory Ventilation

Like IMV, synchronized intermittent mandatory ventilation (SIMV) is a mixture of mandatory and spontaneous or supported breaths but with some added flexibility. Although conventional IMV delivers the mandatory breaths based only on a time trigger, SIMV uses a more complex algorithm to synchronize the mandatory breaths with the patient's own respiratory effort. In effect, there is a window of time based on the set mandatory rate. If the patient makes an inspiratory effort during that window, he will receive an assisted breath (patient trigger but volume, flow, or time cycled). If no inspiratory effort occurs, at the end of the window, the patient will receive a mandatory breath. As with IMV, any breath between these mandatory or assisted breaths may be spontaneous or supported. In reality, many modern ventilators no longer offer even basic IMV; instead they make use of only its synchronized form.

Pressure Support Ventilation

PSV relies on patient effort to trigger every breath. After that, the patient receives support in the form of higher-than-baseline positive airway pressure. The cycle variable is often flow, so if the inspiratory flow drops below a certain rate, this signals that the patient is unwilling or unable to inspire any more, and the airway pressure is decreased back to its baseline level so the patient can fully expire. Alternately, the cycle variable can be pressure, in which case an elevation in pressure beyond

the inspiratory pressure would signal that the patient has stopped inspiring or is trying to actively expire. Baseline expiratory pressure can be positive (PEEP) or zero.

Note that in PSV, if the patient does not initiate a breath, there is no backup mandatory breath built into the mode. Thus, we rely on an apnea alarm to alert us to this life-threatening state, and most ventilators will automatically switch to a mandatory mode after a prolonged period of apnea. Clearly, close monitoring and clinician intervention are necessary with any mechanical ventilation, especially when adjustments and changes in the mode of ventilation are made.

Continuous Positive Airway Pressure

In true CPAP ventilation, all breaths are spontaneous. Regardless of whether the patient is inspiring or expiring, the ventilator maintains the same level of positive airway pressure. The ventilator still monitors flow, volume, and pressure, and displays available spirometric data, but there are no phase variables that are likely to influence ventilator output.

Airway Pressure Release Ventilation

This final mode goes by several names and is probably the most complex to classify because within the same rules for ventilator operation it can be adjusted to fill several clinical roles. One of its names, Bilevel CPAP, describes the mode well when a patient is making an inspiratory effort, but when the patient makes no such attempt at inspiration, airway pressure release ventilation (APRV) functions much like PCV. As is customarily used, a period of high constant airway pressure is cycled alternately with a period of low fixed airway pressure, based only on time as the trigger and cycle variables. Furthermore, there will be no limit or cycle variables that the patient is likely to activate. The overall period of the respiratory cycle tends to be set relatively long, and there is usually an inverse inspiratory to expiratory (I:E) time ratio in which inspiratory time (often called high-pressure time) is significantly longer than expiratory time (often called low-pressure time). Mass movement of respiratory gasses will occur with the switch from high to low pressure and back again, but the patient can also take spontaneous breaths at any time, without causing the ventilator to cycle to a different airway pressure, just as in CPAP.

As another form of a pressure control mode with inverse I:E, APRV has found a small niche providing improved oxygenation and reducing atelectasis at acceptable peak pressures for difficult to ventilate or oxygenate patients (Fig. 54-6). At the other end of the spectrum, it can guarantee a certain amount of gas movement based on the switch between high and low pressure, while permitting spontaneous ventilation at any part of the ventilator cycle. Therefore, it can easily be adjusted to provide CPAP support with a sigh, release, or low rate mandatory PSV breaths built in.

APRV certainly provides a great deal of flexibility in the way that it is applied, but it is not without its hazards. The principal concern with this mode of ventilation is the relatively high mean intrathoracic pressure that is generated. This could apply just as well to any other mode that incorporates high PEEP or high mean airway pressure.

We have not yet discussed the effects of PPV on hemodynamics in much detail, but they can be significant. As positive pressure is applied to all the contents of the chest, the initial effect in some patients may be augmentation of cardiac output and mean arterial pressure for a few seconds mainly due to a brief increase in the pulmonary venous blood flow to the left atrium and a subsequent increase in preload to the left ventricle. However, over a longer period of time, the transmitted positive intrathoracic pressures of PPV will have a much more relevant effect of decreasing cardiac output by impeding flow through the vena cava and pulmonary circulation.[1] There may also be negative effects from the external compression of the aorta, but since similar pressures are applied to both the left ventricle and the aorta at the same time, this is probably a more subtle factor in reducing cardiac output. Naturally, the clinical impact of the decrease in preload in the presence of PPV depends on the magnitude of the maximum, minimum, and mean intrathoracic pressure. This effect can be minimized by ensuring adequate intravascular volume and normal baseline cardiac function. The adverse effect from PPV itself must always be considered in the differential diagnosis for hypotension in the mechanically ventilated patient.

The second main danger of APRV (or any mode of ventilation that uses more inspiratory than expiratory time) lies in the phenomenon of intrinsic or auto-PEEP. This is the process of "stacking" lung volumes from one breath to the next because of inadequate expiratory time. It is most common in patients with obstructive lung disease. This process may be first appreciated by noting that expiratory flow does not return to zero at end expiration. More formally, we can also look for intrinsic PEEP by performing an expiratory hold maneuver in a sedated or paralyzed patient. In this test, at the end of a typical expiratory cycle, the ventilator stops flow. If there is no intrinsic PEEP, then the airway pressure will remain constant during the expiratory hold, but if there is significant airway obstruction and intrinsic PEEP, then the alveolar pressure will continue to equilibrate with the pressure in the ventilator tubing, and the measured airway pressure will increase during the hold maneuver.

It should be noted that this test will be unreliable and uncomfortable for a patient who is making respiratory effort. Because it is caused by poor emptying of the alveoli and produces alveolar pressures that are higher than the measured expiratory airway pressure, this phenomenon of intrinsic PEEP can lead to high intrathoracic pressure that is not necessarily reflected in the measured expiratory pressure on the ventilator display, so the clinician must be

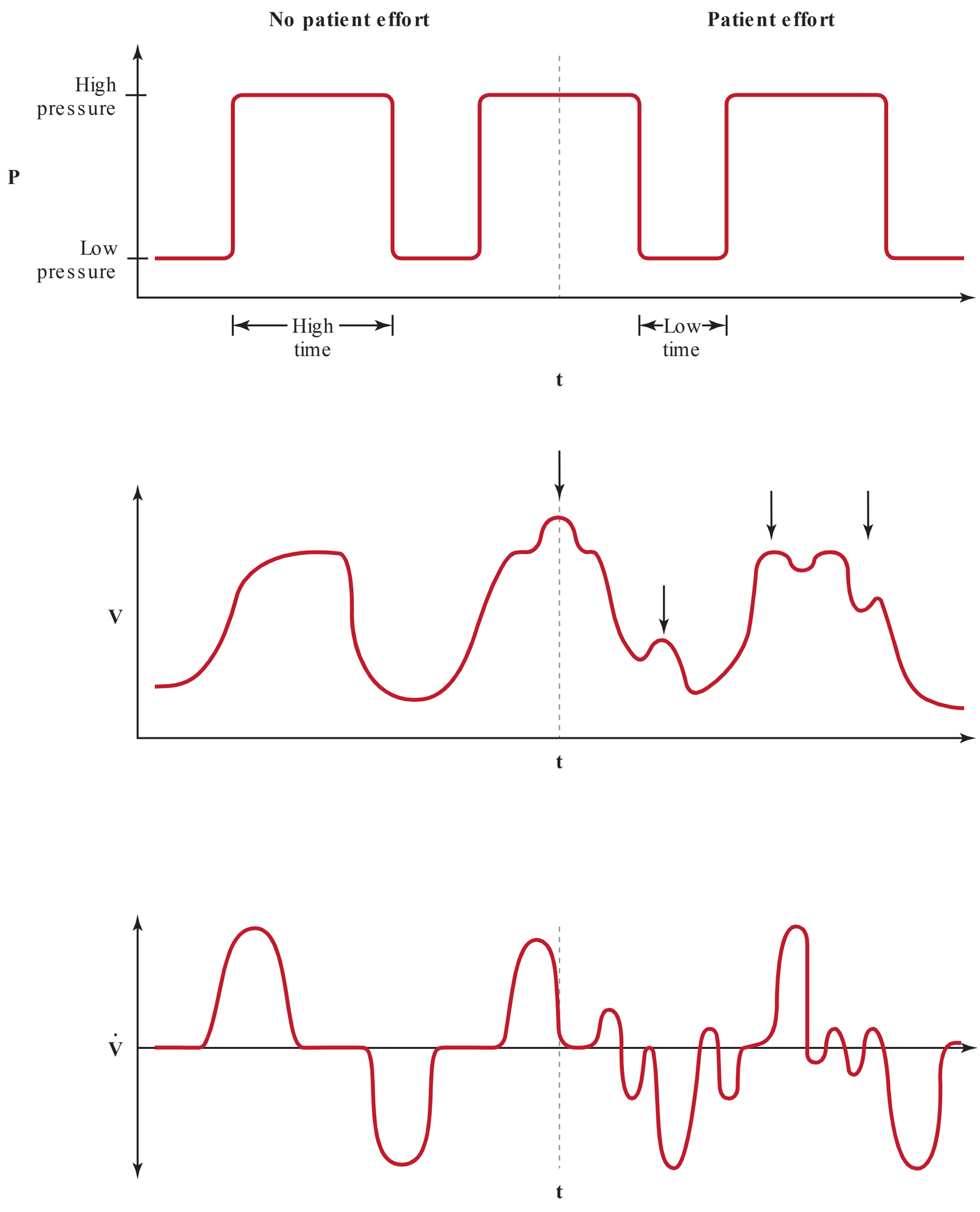


FIGURE 54-6 Pressure, volume, and flow versus time for APRV with and without patient effort (right and left sides, respectively).

vigilant to detect it. At its extreme, high intrinsic PEEP can cause pulseless electrical activity and cardiac arrest by an enormous reduction in venous return to the heart, but the short-term solution is as simple as disconnecting the endotracheal tube from the ventilator to allow full expiration and restore lifesaving preload and cardiac function (Fig. 54-7).

CLINICAL APPLICATION

Now that we have constructed a catalog of the most commonly used modes of ventilation, we will explore how they can be used practically by considering two clinical scenarios.

Scenario 1: An Obese Woman with a Surgical Complication

In the first scenario, our patient is a 56-year-old woman with hypertension and diabetes, but no lung disease, who came to our hospital for an elective laparoscopic gastric bypass procedure. She is 168 cm tall (66″) and weighs 130 kg (286 lb). After intravenous induction of general anesthesia, an endotracheal tube is inserted without incident, and we begin to ventilate the patient. For the procedure, she is under general anesthesia. To meet the needs of the surgeon and for improving our ease of ventilation, we will also keep her paralyzed with a nondepolarizing neuromuscular blocking drug for most of the case.

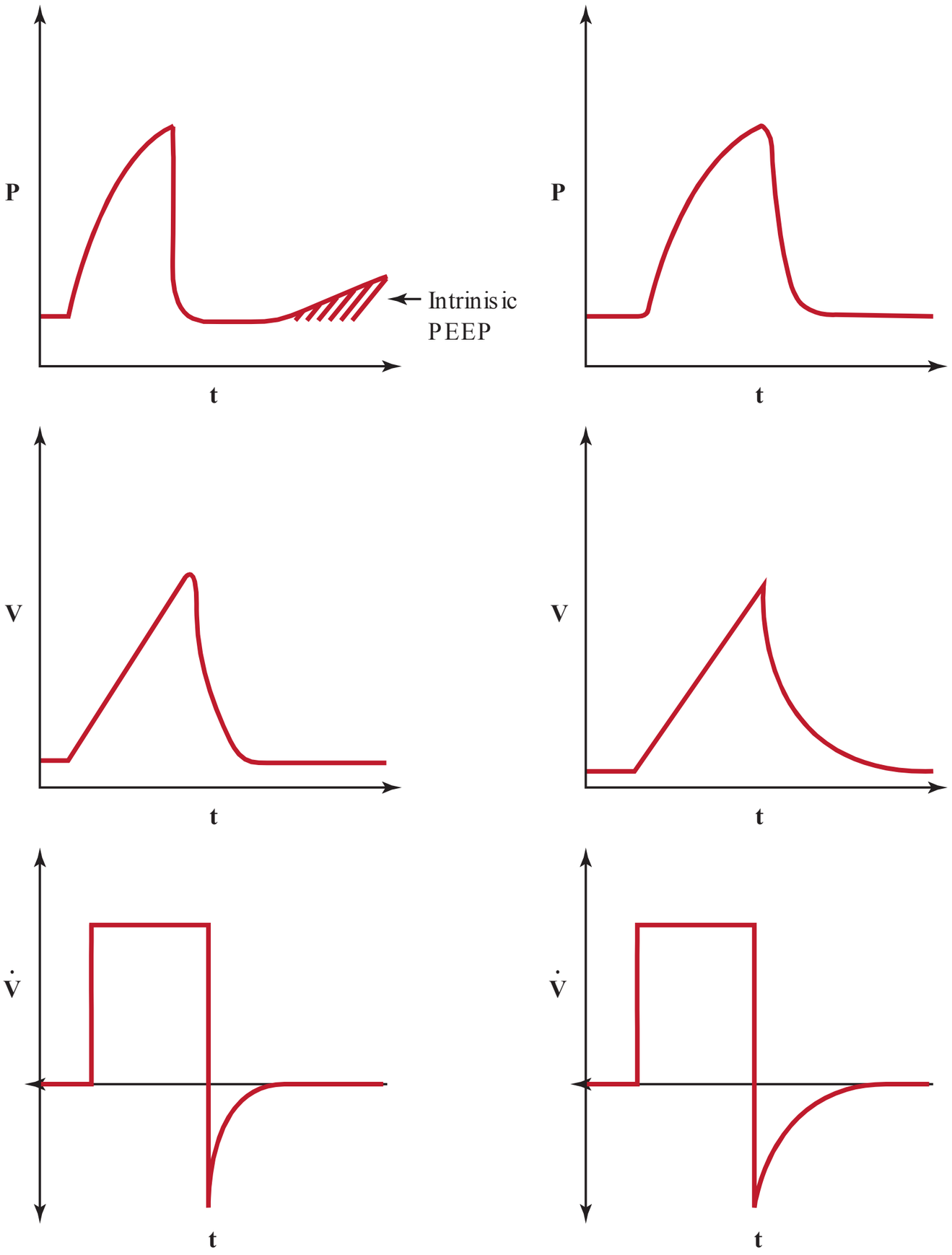


FIGURE 54-7 Pressure, volume, and flow versus time during expiratory hold maneuver for patient with (left) and without (right) intrinsic PEEP.

Question: How will we set up the anesthesia ventilator? Because the patient is paralyzed and under general anesthesia, we will want a mode of ventilation that relies on mandatory breaths. As we do not know anything about her initial lung compliance, we choose a VC-CMV mode that is just called VC on the menu of our anesthesia ventilator. Our routine is to initiate ventilation with V_T of about 8 mL per kg of body weight (8 mL/kg × 130 kg = 1040 mL), but since this patient is obese, we will use ideal body weight in the calculation (8 mL/kg × 62 kg = 496 mL) and start ventilation with V_T of 500 mL and a respiratory rate of 12 breaths per minute. This yields a minute ventilation of about 6 L which seems reasonable. By convention, we will start the ventilation immediately after induction of anesthesia with a fraction of inspired oxygen (FIO_2) near 100 % (pure oxygen).

As it turns out, the patient's metabolic needs are even less under general anesthesia than we had predicted. We have decreased the FIO_2 to around 50%, and the pulse oximeter is still hovering near 100%. A few minutes after we begin ventilating the patient, we also notice that the partial pressure of expired carbon dioxide (end-tidal CO_2 or $ETCO_2$) is only 28 mm Hg, while we would expect it to be around 35 in a normal patient (allowing for approximately 5 mm Hg gradient between arterial and alveolar CO_2 concentration). Most likely we have caused a respiratory alkalosis by hyperventilating the patient, so we titrate the rate downward and eventually find that a respiratory rate of 10 breaths per minute is just right to keep the $ETCO_2$ around 35 where we want it. Alternately, we could have decreased the V_T. Everything is running smoothly as the patient is prepped and draped, but soon we meet our first challenge as the surgeon makes a small incision and begins inserting her laparoscopic ports and insufflating the patient's abdomen. Because this patient is obese and has such a thick abdominal wall, the surgeon requires an intra-abdominal pressure of at least 15 cm H_2O to form the space in which she will work. This same pressure is transmitted up against the diaphragm, and now at our settings of V_t = 500 on the volume control mode, we find that

the peak airway pressure has risen from about 25 cm H_2O to well over 40. Because we are concerned that this high level of positive airway pressure can impede venous return to the heart, worsen mismatch of ventilated and perfused zones of the lungs, and perhaps even cause direct injury to the lungs, we would like to find a ventilation strategy that can provide the same or better ventilation at lower airway pressures.

In this case, we feel confident that the timing and magnitude of this increased airway pressure is related to insufflation of the abdomen rather than any intrinsic pulmonary disease, so we do not plan to investigate it further. If we were unsure about the source of the increased airway pressure though, we could gather more information by performing an inspiratory hold maneuver. Recall that in the equation of motion for the respiratory system, there is a static component from lung elastance and a dynamic component in the form of airway resistance. During inspiration, we observe an increase in airway pressure that depends on both of these variables. In the inspiratory hold however, we stop flow at the end of a typical inspiratory cycle and look at the airway pressure when there is no flow. This value is called plateau pressure. Without any flow, the airway pressure is only due to the elastance of the system ($P = EV$), so if plateau pressure is very close to peak pressure, then we know that resistance must be low, and most of the observed airway pressure during inspiration is due to elastance. This would presumably be the case with our patient with decreased lung compliance secondary to increased intra-abdominal pressure. On the other hand, if the plateau pressure is much lower than the peak pressure, then *resistance* to airflow (ie, the part of the total airway pressure that we have removed in this maneuver) is probably contributing most of the increase in peak airway pressure. Bronchospasm would be an example of increased peak airway pressure due to increased resistance. This distinction is also relevant because we think that the plateau pressure is more closely linked to the development of lung injury from high pressure or stretch injury than peak pressure is.

Question: How can we keep from exceeding a reasonable airway pressure while still ventilating the patient well? We have decided that we would like the peak airway pressure to be less than 30 cm H_2O for this patient, so we try a pressure control version of CMV. We also want to minimize atelectasis from the high intra-abdominal pressure, so we will add a small amount of PEEP, such as 5 cm H_2O. Now we set the inspiratory pressure at 25 cm H_2O and see what volume results. This change alone ends up giving the patient 450 mL V_T at much lower pressure. Part of this benefit is that, like many ventilators, the one attached to our anesthesia machine uses a different waveform for PCV compared with VCV. The square pressure wave and descending flow wave of PCV means that the peak pressure is the same as the mean, and we get the maximum volume out of that peak by holding it throughout the entire inspiration, whereas our VCV mode had been using a square flow wave that results in an upward slanted pressure wave with a higher peak for the same mean value. We again titrate the rate to attain an end-tidal CO_2 around 35. At a rate of 14, we find that we are adequately ventilating the patient without exceeding our goal high-pressure limit (Fig. 54-8).

From this point on, we find that the ventilatory needs of the patient are pretty stable. Unfortunately, about 2 hours into the case, we learn suddenly that a complication has occurred. The surgeon has inadvertently damaged some vascular structure—perhaps it is the splenic artery—and brisk bleeding ensues. Within a few minutes, she has converted to an open laparotomy, but not before the patient has lost a large quantity of blood. The patient

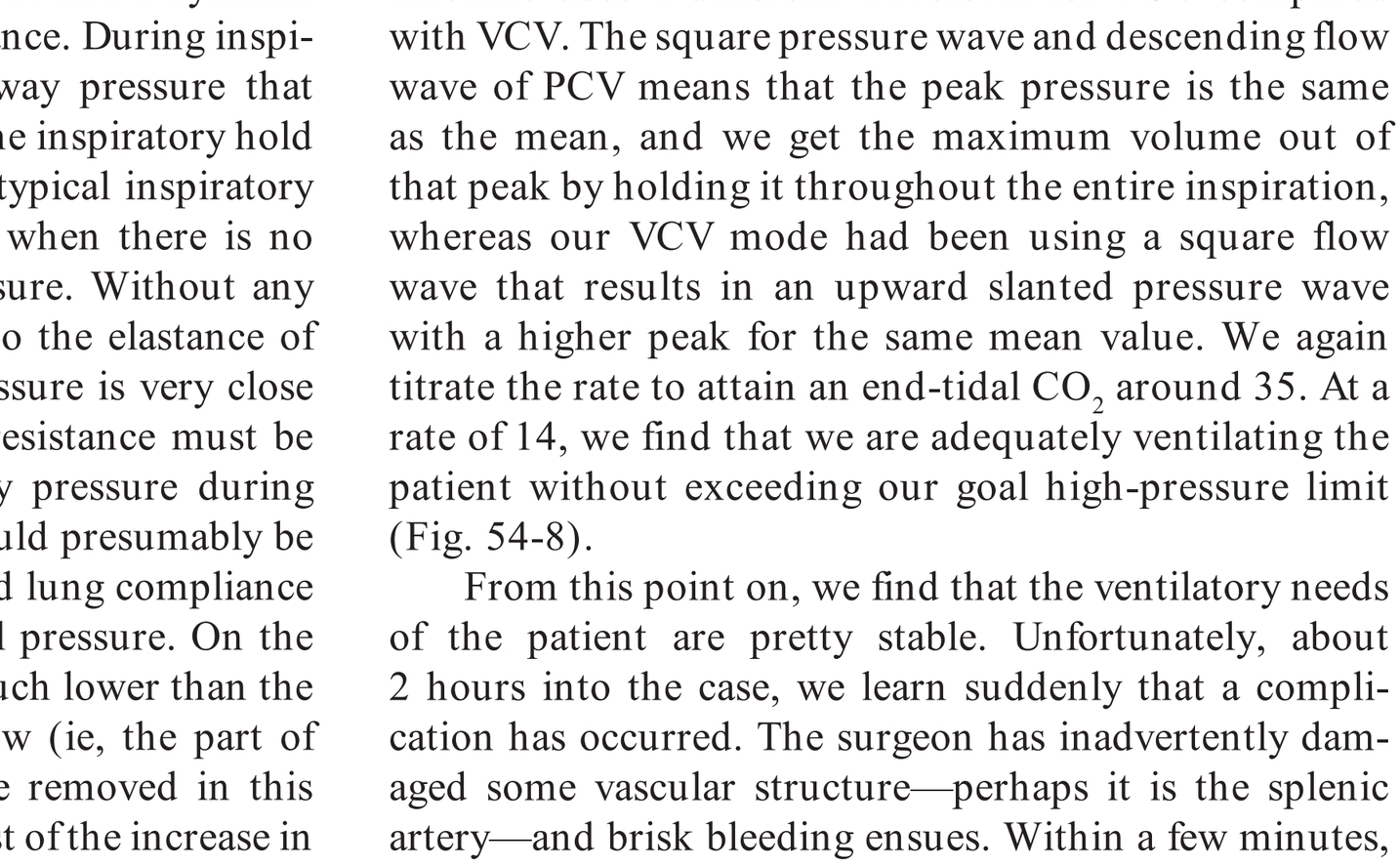


FIGURE 54-8 Comparison of square pressure wave and square flow wave.

becomes hypotensive and eventually loses about 2.5 L of blood. Furthermore, she ends up requiring transfusion of several units of blood products, 1 L of colloid, and, by the end of the case, about 8 L of crystalloid fluids. The bleeding is stopped and the case completed by way of the laparotomy, but as the surgeon begins to close, the patient continues to require at least 75% FIO_2 to keep pulse oximetry above 92%, and because we appreciate diffuse rales on auscultation of the lungs, we suspect she has acute pulmonary edema. Hopefully, this is just from aggressive volume resuscitation in the face of some diastolic dysfunction from her longstanding hypertension, rather than any new problem like myocardial infarction. Postoperative chest X-ray and electrocardiogram (EKG) in the postanesthesia care unit (PACU) seem to support this diagnosis, but regardless of the cause, the patient is not tolerating low enough FIO_2 to extubate. She will stay in the ICU for diuresis and ongoing mechanical ventilation. She is lightly sedated overnight, but is making respiratory efforts, so neither of the modes of ventilation that we have used so far seems appropriate.

Question: What mode of ventilation is appropriate for a lightly sedated patient in the ICU? We have several options here, but because difficulty in weaning FIO_2 is going to keep the patient mechanically ventilated for the time being, we will choose volume control A/C. We try V_T of 500 mL, mandatory rate of 10 breaths per minute, and continue PEEP of 5 cm H_2O and the same 80% FIO_2 that we were using in the PACU.

An initial arterial blood gas (ABG) shortly after arrival at the ICU confirms good correlation between the laboratory measurements and our pulse oximeter's estimate of oxyhemoglobin saturation, so we will titrate the FIO_2 downward as tolerated based on bedside pulse oximetry. The ABG also shows that the patient has a mild respiratory acidosis with arterial partial pressure of carbon dioxide ($PaCO_2$) of 48 mm Hg, but since the time that the sample was drawn, we notice that she has begun triggering a few extra assisted breaths every minute, in addition to the mandatory rate of 10, and in this way she is increasing minute ventilation to meet her own needs.

By the time we see the patient the next morning, she has diuresed several liters of urine with corresponding improvement in her chest X-ray and lung examination, and she is tolerating 40% FIO_2. She is arousable and appropriate in her interaction and occasionally initiates an assisted breath. Cardiac enzymes and EKG have continued to be normal, and she is normotensive on maintenance fluids and without any pressor medications. It seems that she may be able to tolerate extubation, but we would like to see how well she takes over the work of breathing before we actually remove the endotracheal tube.

Question: What mode of ventilation can we use to predict whether the patient will tolerate extubation? Again, we have several options here, but for this patient who has been reliant on mechanical ventilation for less than a day, we can probably jump straight to a trial of low-level pressure support or even CPAP. We quickly see that she does fine on PSV with FIO_2 of 50%, inspiratory pressure of 10 cm H_2O, and PEEP of 5 cm H_2O. We feel confident that she will be successfully extubated at this point but proceed to a trial of CPAP at 5 cm H_2O. With this minimal assistance, she is able to take 350 to 450 mL V_T at a rate of 18 breaths per minute for almost an hour.

Question: How can we predict which patients will tolerate extubation? There are several indices that have some predictive value in determining which patients will succeed after extubation and which will require reintubation and continuation of mechanical ventilation. In general, we would like to see that the patient is able to take large breaths, is comfortable breathing slowly, and produces adequate minute ventilation. Sedating medications should be stopped before the extubation is performed. One of the best-validated indices that encompasses several of these variables is the rapid-shallow breathing index. It is defined as respiratory rate divided by V_T in liters (RR/V_T). When it is above 105, it predicts failure at extubation, and when it is less than 105 it predicts success after extubation.[2] For our patient, this index is 18/0.4 L or 45, so we feel fairly confident that if we extubate her she will flourish. We do, and she does.

Scenario 2: An Elderly Veteran with Pneumonia

Our next patient is a 69-year-old man who is a two-pack-per-day smoker but has no other past medical history (though he admits he has not seen a doctor in many years). He is 180 cm tall (71″) and weighs 75 kg (165 lb). We meet him when he presents to the emergency department of the local VA Hospital. He says that he has been feeling ill for about 3 days, with a progressive cough, shortness of breath, and fever. His wife notes that he is having chills for the past 2 days. He did not want to seek care, but he can no longer even walk to the bathroom in his house without becoming severely dyspneic and lightheaded. At this point, his respiratory rate is 36 breaths per minute at rest, and he is visibly straining and using accessory muscles of respiration. Auscultation of the lung fields reveals both wheezing and diffuse rhonchi. Pulse oximetry does not seem to be working well, presumably because of his poor peripheral perfusion (his hands are cold and a little bluish), but it is yielding numbers that are generally between 75% and 85%. He continues to have apparent respiratory distress despite the 100% non-rebreather oxygen mask that we started on his arrival at the emergency department, so after a very brief discussion with him and his wife, we make a clinical decision to secure the airway and mechanically ventilate him in the hope that this will provide adequate oxygenation. Intubation proceeds without incident, and we manually ventilate the patient while waiting for a ventilator to be set up at the bedside. In the

meantime, his ABG results come back showing the following values.

pH	7.50
PaO_2	62 mm Hg
O_2 saturation	93%
$PaCO_2$	42 mm Hg
HCO_3	32 mmol/L
FIO_2	100%

We interpret this ABG as severe relative hypoxemia (given the pure oxygen he is breathing) with metabolic alkalosis and perhaps a small amount of respiratory compensation, but given this patient's clinical history as a lifelong smoker who now has a prototypical history of pneumonia, we speculate that these values are most consistent with acute hypoxemic respiratory failure from his pneumonia and reversal of his chronic respiratory acidosis due to a hypoxemic respiratory drive but persistence of the compensatory metabolic alkalosis. The ventilator arrives and we initiate A/C with 100% FIO_2, V_T of 600 mL (8 mL/kg × 75 kg), respiratory rate of 20, and PEEP of 5 cm H_2O. Chest X-ray is performed to examine the lung fields and check endotracheal tube placement, and it shows diffuse bilateral pulmonary infiltrates. EKG shows some nonspecific T wave inversion but a sinus rhythm, cardiac auscultation reveals only distant heart sounds without any other abnormality, and there is no other indication of cardiac disease. Because the patient is hypotensive, tachycardic, tachypneic, and febrile, he clearly meets criteria for sepsis syndrome and we place a central venous catheter to monitor his central venous pressure. This turns out to be low at 2 cm H_2O, so again, we have no indication that the patient has heart failure or volume overload causing his pulmonary infiltrate.

Question: Does this patient have acute lung injury (ALI) or acute respiratory distress syndrome (ARDS)? ARDS is characterized by acute onset of severe respiratory distress; bilateral infiltrates on frontal chest radiograph; no quantitative or clinical signs of left heart failure; and severe hypoxemia. The hypoxemia is further quantified by calculating the ratio of arterial partial pressure of oxygen or PaO_2 (expressed in millimeters of mercury) to FIO_2 (as a decimal, that is, 100% = 1 or 21% = 0.21). If it is less than 300, this defines ALI, and if it is less than 200, this defines ARDS.[3] Our patient certainly meets all the criteria above, and when we calculate the ratio of PaO_2 to FIO_2 we get 62 (62/1.0), so the patient has ARDS. It is interesting to note that aside from excluding volume overload or congestive heart failure, the precise etiology of the ARDS is not really considered in the definition. In our case, the patient probably has a primary pulmonary process, but if his ARDS were the result of an extrapulmonary infection, pancreatitis, or any number of other causes, we would still classify and treat his disease similarly.

Question: How do we ventilate differently for the patient with ARDS? The cornerstone of ventilation for patients with ARDS and ALI is with low V_T. Traditional V_T with mechanical ventilation had been 10 to 15 mL per kg IBW, but in 2000, the results of the ARDS Network study of low V_T established that by limiting V_T to around 6 mL per kg IBW rather than the usual 12 mL per kg, mortality in patients with ARDS could be reduced from around 40% to around 30%.[4] This was despite generally increased hypoxia and hypercapnea in the reduced V_T group. Part of the basis of this benefit is thought to be due to limiting pressure injury (barotrauma) or stretch injury, so we also monitor plateau pressure regularly in patients with ARDS and strive to keep it below 30 cm H_2O. For our example patient, we have already selected a V_T of 8 mL per kg IBW, which is reasonable, but we find that he is still having peak airway pressures well over our goal of 30 cm H_2O. When we perform an inspiratory pause, we find that the plateau pressure is also 32, so the high peak pressures are due in large part to a problem with lung compliance rather than an obstructive process. We further decrease our V_T, and we find that at a V_T of 450 mL we can keep plateau pressure well below 30.

Although we are using evidence-based ventilatory strategies in our patient with ARDS, he does not do well. We have initiated broad antibiotic therapy for his community-acquired pneumonia and adequately resuscitated him, but he continues to have refractory hypoxemia and we are unable to wean him from 100% inspired oxygen. Repeat ABG on the second day of his hospitalization shows that pH is more normal as his bicarbonate level has decreased from the previous day, but the severe hypoxemia persists with PaO_2 of 58% on 100% FIO_2. The persistence of hypoxemia on 100% FIO_2 for over an hour is sometimes used to define refractory hypoxemia.[5]

Question: How can we treat refractory hypoxemia? Perhaps the better question is should we treat refractory hypoxemia? Our answer is probably, yes. Despite the very high mortality in cases like this example, it is plausible that quality of life could be improved and permanent organ damage reduced in survivors by minimizing time spent with severe hypoxemia. There are a few simple strategies such as conservative fluid management and higher PEEP and many more creative techniques including high-frequency oscillatory or percussive ventilation, APRV or the related mode of pressure control inverse ratio ventilation (PC-IRV), addition of inhaled nitrous oxide or other vasodilators to the inspired gas mixture, prone positioning, use of neuromuscular blocking agents, and perhaps corticosteroid administration to name just a few that offer some improvement in oxygenation. Sometimes this improvement is brief, but for other interventions, there is reasonable evidence that it can persist for days after the intervention is completed. Unfortunately, regardless of whether oxygenation is improved or not, we know of no ventilatory or nonventilatory technique for improving

refractory hypoxemia that has been well established as also improving survival. For this reason, it is worth trying the techniques that are safe and available, but it becomes hard to defend them as they become more risky and expensive.

We try to achieve better oxygenation using neuromuscular blockade and PC-IRV for 2 days. Oxygenation does improve and we wean to 70% FIO_2, but by day 5, the patient is back to the same high requirement for inspired oxygen and full mandatory ventilation despite the fact that we are now well on the way toward fully treating his sepsis and pneumonia. He has stable hemodynamics and improvement of his fever and leukocytosis. After 2 weeks in the ICU and a tracheostomy, we still do not see improvement in respiratory function. The patient becomes tachypneic and his oxygen saturation drops anytime his sedation is reduced, he is not very interactive with staff or family even when he is not sedated, withdrawing to pain but not communicating otherwise. We cannot offer a very encouraging prognosis, and his family expresses concerns that his current state of disability would seem undignified and be undesirable to him. After a long discussion, we reduce care to comfort measures and withdraw ventilatory support to supplemental oxygen by tracheostomy mask only. The patient dies later that day.

CONCLUSION

Hopefully this chapter has enriched readers' understanding of the physiologic, pathophysiologic, and engineering basis of mechanical PPV. With this strong foundation, variations on the currently widespread styles of ventilation should be very understandable. As the cases illustrate, there are numerous ways to apply ventilation technology, and even when we do it well, we may not be guaranteed a good outcome. Perhaps the most ideal applications of this technology will be to pause the process of dying, giving us a brief time to search for underlying problems that can be corrected. The techniques described above should provide a generous selection of tools that clinicians can adapt to support a patient in the meantime.

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CHAPTER

55 Complications of Intubation: Acute and Chronic

Charles J. Lin and Manuel C. Vallejo

INTRODUCTION

Intubation is the most commonly used method of securing a patient's airway during surgical procedures and is a mainstay of management of patients in acute respiratory failure or who have altered mental status. Complications of endotracheal intubation can result from direct laryngoscopy, from pressure of the endotracheal tube or cuff on the airway and on surrounding structures, and from extubation.[1] There are numerous structures in the oropharynx, laryngopharynx, larynx, and trachea that are susceptible to potential damage (Fig. 55-1). This chapter discusses notable complications of endotracheal intubation, as well as their precipitating causes and perioperative management. These can be subdivided temporally: acute or chronic, depending on whether they occur at the time of intubation or whether they occur secondary to prolonged intubation.[2] Table 55-1 provides a comprehensive list of acute and chronic complications; a number of these are discussed in detail in this chapter.

PREDISPOSING FACTORS

Several factors are likely to increase the risk of pharyngeal and laryngeal complications. These factors may be related to the skills of the provider, the airway equipment, the patient's anatomy, the emergent nature of the intubation, unanticipated difficulty encountered during intubation, or a combination of these. The provider plays a role in the risk of endotracheal intubation based on his or her knowledge, skill, and experience.[2] In addition, the equipment used for endotracheal intubation can affect the outcome. An inappropriately sized endotracheal tube, or the use of stylets or bougies, increases a patient's risk of airway trauma.[2] The provider's initial evaluation of the airway is a key element in avoidance of, and preparation for, a difficult intubation and the airway trauma that may result from it. Patient-related risk factors for airway trauma related to endotracheal intubation include a small larynx, cervical spine pathology, and difficult airway as assessed by the Mallampati score. It is also important to be mindful that routine intubation can cause trauma to the laryngeal soft tissues; a closed claims study demonstrated that 80% of laryngeal injuries occurred during routine intubation.[3,4] Therefore, under the best circumstances and in the hands of the most experienced operator, complications may still occur.

FAILED OR MISPLACED INTUBATION

Failed or misplaced intubations are some of the most commonly encountered complications of endotracheal intubation. Incorrect placement of the endotracheal tube may result in esophageal or bronchial intubations, which must be recognized and corrected promptly. Esophageal intubation may be recognized simply by auscultation of air in the abdomen, and lack of breath sounds, or lack of persistent end-tidal carbon dioxide ($ETCO_2$) with ventilation. Of note, transient $ETCO_2$ can be detected despite an esophageal intubation if the patient recently consumed a carbonated beverage. Sequelae of esophageal intubation are serious including hypoxia, brain death, myocardial infarction, and cardiac arrest.[5–7]

Bronchial intubation occurs when the endotracheal tube is placed in one of the mainstem bronchi, usually on the right due to its more vertical orientation as compared with the left. Infants and children are at higher risk of bronchial intubation due to the smaller distance between the vocal cords and carina. An endobronchial intubation can occur immediately after intubation, when the endotracheal tube is advanced too far. Endobronchial intubation only ventilates and oxygenates one lung, which leads to atelectasis, ventilation-perfusion mismatch, and hypoxia. If the patient has unequal breath sounds in both lungs, the endotracheal tube can be slightly pulled back. During the surgery or in the intensive care unit, the endotracheal tube is also at risk of migrating into a bronchus when the patient's position is changed. For example, placing a patient in the Trendelenburg position can advance a tube that was initially in the distal trachea into the right mainstem bronchus.[8] Usually, this event presents as elevated airway pressures and oxygen desaturation. Knowing the original depth of the tube when correct placement was confirmed can be useful for determining the length of endotracheal tube to pull back.

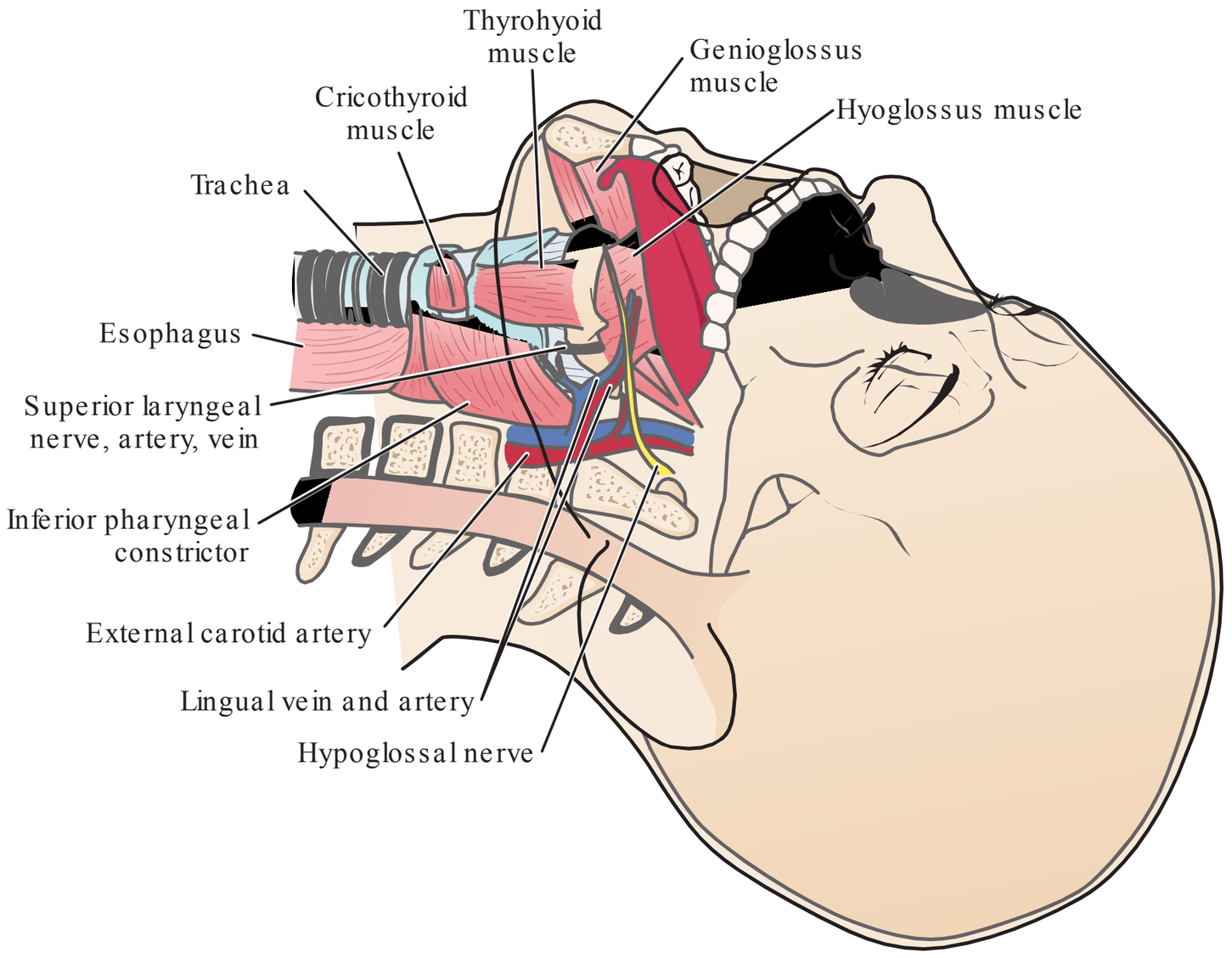


FIGURE 55-1 Structures that are at risk of harm during endotracheal intubation.

(Adapted from Ferson D, Chi L, Zambare S, et al. Safety and hazards associated with tracheal intubation and use of supralaryngeal airways. In: Gravenstein N, Kirby RR, eds. Complications in Anesthesiology. 2nd ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2006:109–124, with permission.)

Table 55-1

Complications of Endotracheal Intubation

Acute complications of endotracheal intubation
Failed intubation
Esophageal perforation
Difficult intubation
Hyperactive autonomic response
Spinal cord injury
Corneal abrasion
Trauma to oropharyngeal soft tissue
Dental injury
Hoarseness and vocal cord damage
Tracheobronchial damage
Bronchospasm
Laryngospasm
Passive reflux and aspiration
Airway edema with postextubation obstruction
Chronic complications of intubation
Tracheal stenosis
Tracheoesophageal fistula
Tracheomalacia
Sinusitis and nasal ulceration from nasal intubation
Oral ulceration
Laryngomalacia

ESOPHAGEAL TEAR OR RUPTURE

Esophageal perforation is a rarely reported complication of endotracheal intubation that occurs during unintentional esophageal intubation.[9–14] Most iatrogenic esophageal injuries occur during upper gastrointestinal endoscopy and esophageal dilation and usually involve the thoracic esophagus.[15] However, esophageal injuries that occur secondary to endotracheal intubation are usually located in the cervical esophagus. The increased susceptibility of the cervical esophagus to injury is due to the lack of a reinforcing longitudinal muscle layer and the pressure of the cervical vertebrae on the esophagus during cricoid pressure and neck hyperextension.[10] Hilmi et al[10] published two cases reporting the occurrence of subcutaneous emphysema after unintentional esophageal intubation (Fig. 55-2). In both cases, perioperative endoscopy identified an esophageal tear in the posterior wall, in the cervical esophagus near the upper esophageal sphincter. Risk factors for esophageal perforation include operator experience, unanticipated difficult intubation, and the use of a rigid stylet.[10,16] The most common clinical finding of esophageal perforation is subcutaneous emphysema in the neck or upper chest that becomes more obvious when the patient receives mask ventilation.[10] The extent of the subcutaneous emphysema depends on the amount of air that enters the esophagus; patients who are readily ventilated will have less air entry into the esophagus than patients who are difficult to mask ventilate. Appropriate diagnostic tests include a chest radiograph and endoscopy for definitive diagnosis. Depending on the location, extent of the injury, development of

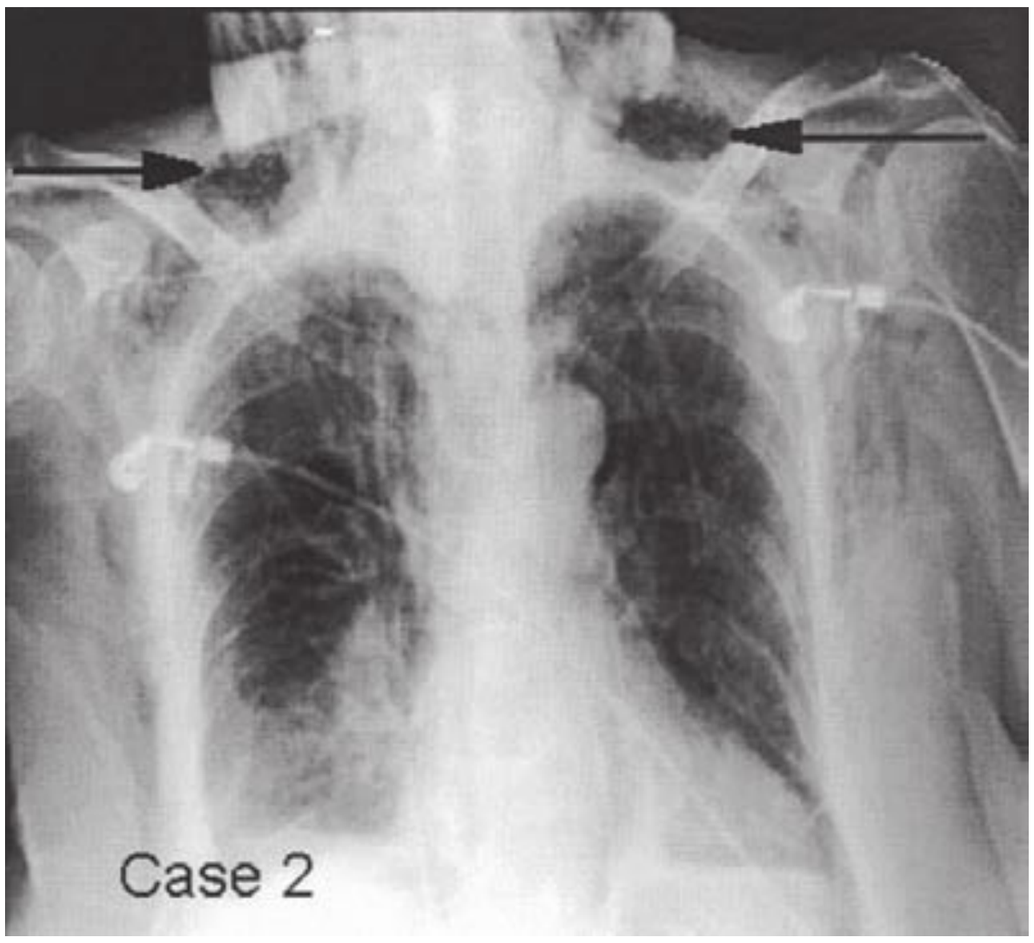


FIGURE 55-2 Subcutaneous emphysema in supraclavicular area.

(Reused with permission from Hilmi IA, Sullivan E, Quinlan J, et al. Esophageal tear: an unusual complication after difficult endotracheal intubation. Anesth Analg. 2003;97:911–914.)

sepsis, and the patient's overall medical condition, conservative nonsurgical management is generally preferred unless complications arise.[10] Conservative management includes antibiotics, nasogastric suction, and total parenteral nutrition.

DIFFICULT INTUBATION

This important topic is discussed fully in other chapters of this book. (See Chapters 9–15.)

AUTONOMIC HEMODYNAMIC RESPONSE

Both laryngoscopy and intubation can trigger the body's sympathetic response, resulting in an increase in circulating catecholamines. This, in turn, can cause hypertension, various arrhythmias, increased intracranial pressure, and increased intraocular pressure. These complications could potentially lead to myocardial ischemia or infarction, congestive heart failure, or fatal arrhythmias.[17] Risk factors for these complications include history of cardiovascular disease as well as prolonged laryngoscopy or multiple attempts at intubation. Medications frequently used to reduce the impact of these autonomic reflexes in an adult include pretreatment doses of intravenous lidocaine (50 mg) or intravenous fentanyl (100 to 200 mcg). The administration of short-acting beta-blockers such as esmolol before laryngoscopy can control hemodynamic responses to endotracheal intubation and prevent tachycardia.[18]

INJURY TO THE VERTEBRA(E) OR SPINAL CORD

Injury to the spinal column or cord can occur with hyperextension of the cervical spine during intubation. In its worst case, it can result in quadriplegia. Patients most at risk of this complication include those with a history of cervical spine fracture, previous surgery to the cervical spine, tumors of the cervical spine, spinal malformations, osteoporosis, and trauma with suspected instability of the cervical spine.[2] For patients in these categories, the provider should consider fiberoptic intubation, or another means of managing the airway that would avoid significant cervical spine motion (see relevant chapters in the book on fiberoptic bronchoscopy for intubation, optical stylets, lightwands, prism/mirror-based devices, and rigid fiberoptic devices).

CORNEAL ABRASION

Corneal abrasion is a preventable complication of airway management that carries an incidence of 0.1% in nonophthalmologic surgery, though the etiology is not always apparent.[19] This complication can be caused by objects on the provider's wrist or hanging from the provider's neck or uniform chest pocket such as jewelry, a wristwatch, or an identification badge, resulting in direct trauma to the corneal epithelium.[20] One measure that can be used to protect the patient's eyes during mask ventilation and intubation is to tape the eyelids closed after induction and before laryngoscopy. Soothing saline drops or methylcellulose drops overnight can manage a simple abrasion. For those with severe pain or changes in visual acuity, an ophthalmology consultation should be obtained. Antibiotics are usually not required, and patients are usually symptom-free the following morning.

TRAUMA TO THE OROPHARYNGEAL SOFT TISSUE

The incidence of oral and pharyngeal injury during endotracheal intubation can be as high as 18%.[21] Although not usually severe, trauma to the lips, teeth, tongue, and buccal mucosa may be painful and are of cosmetic concern to the patient. These types of injuries are more common with difficult intubations or poor laryngoscopic technique especially among beginners.[22] Patients may complain of dysphagia or sore throat postoperatively. If the mucosal

lining of the posterior pharynx is disrupted, a pharyngeal abscess may develop.[23]

DENTAL INJURIES

Dental injuries are the most common complication of endotracheal intubation and the most common reason for lawsuits against anesthesiologists.[24–30] Retrospective data demonstrate that the incidence of dental injuries ranges from 0.02% to 0.07%, but prospective studies show that the incidence is higher ranging from 0.1% to 12% especially at hospitals with anesthesiology training programs.[21,31–33] The greatest risk occurs during direct laryngoscopy, and the anterior maxillary teeth are the most commonly damaged. This occurs when the proximal end of the laryngoscopic blade is placed on the anterior maxillary teeth, and the teeth are used as a fulcrum in an attempt to secure a better view.[27] Another major cause of dental damage is the placement of an oral airway in the oropharynx, which can expose vulnerable teeth to injury secondary to the forces of clenching, grinding, and mastication during emergence.[34,35] A soft roll of gauze can be used instead; it should be placed on healthy posterior teeth to withstand excessive forces that can occur during emergence.[27]

During the preoperative evaluation, the patient's dentition should be evaluated and any teeth that appear chipped, loose or previously repaired should be documented with the tooth numbered according to the universal numbering system for adult dentition (Fig. 55-3). Buffington and Vallejo[36] developed a simpler method for numbering teeth by focusing on the anterior teeth, the most likely damaged, and using a memory trick "6,11 × 2 = 22,27" to help providers remember how to number teeth (Fig. 55-4). Tables 55-2 and 55-3 provide a list of characteristics that place patients at a high risk of dental injury. Teeth that have been restored with fillings, caps or crowns, or corrected with a root canal are still weaker than healthy teeth and are susceptible to fracture or dislodgement when an undue stress is applied to them.[21,26,37] To prevent aspiration and to aid the retrieval of dislodged dentition, loose teeth can be secured by wrapping 3-0 silk suture around the gingival margins of the tooth and taping the suture to the ipsilateral cheek (Fig. 55-5).[27] Pediatric patients may have loose deciduous teeth that should be removed after the induction to prevent the risk of a traumatic dislodgement causing an airway obstruction or harm to the underlying permanent tooth. Several studies have examined the use of mouthguards to protect teeth during laryngoscopy. Some concerns about mouthguards are that the thickness of the guard impedes visibility of the oral cavity and decreases the amount of space in the mouth, and their use may prolong intubation time with an increased risk of oral trauma.[27] In fact, mouthguards have not demonstrated any significant decrease in dental injury.[38]

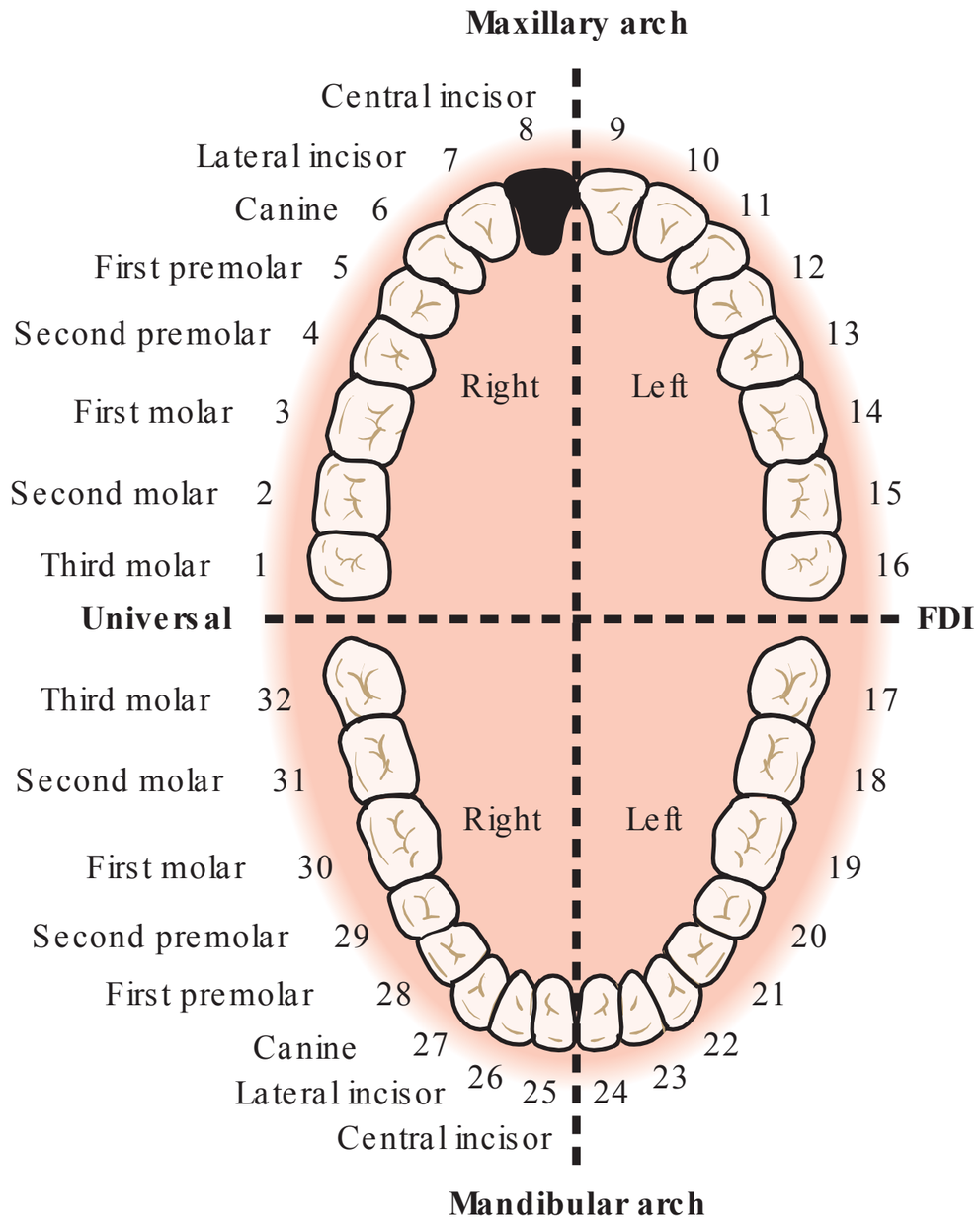


FIGURE 55-3 Universal numbering system for adult dentition.

(Adapted from Yasny JS. Perioperative dental considerations for the anesthesiologist. Anesth Analg. 2009;108:1564–1573, with permission.)

If dental trauma occurs during intubation, the dental service should be consulted postoperatively. If the tooth is dislodged, its retrieval is mandatory prior to placing the endotracheal tube. Chest X-rays can be used to locate the missing tooth. The concern is that the dislodged tooth can be wedged into a bronchus. If the tooth cannot be retrieved manually, a fiberoptic bronchoscope is used to retrieve the tooth. Leaving the tooth in the pulmonary tree can lead to hypoxemia, lung collapse, and the formation of a lung abscess.[1] If the tooth is loosened, it should be secured with tape or suture in its original position. If the tooth is avulsed, the decision to reimplant the tooth is under the discretion of the anesthesiology team. The benefit of immediate reimplantation is the increased likelihood of successful retention; however, the concern with reimplantation is the risk of aspiration. If the tooth is reimplanted, do not wipe or dry the root surface because it contains a collagen network that is necessary for reimplantation.[39] If the tooth is not immediately reimplanted, the preferable soaking solution is milk.[40] The other alternative is normal saline.[40] The dental injury should be reported to the risk management department, and details of the incident should be documented on the patient's chart.

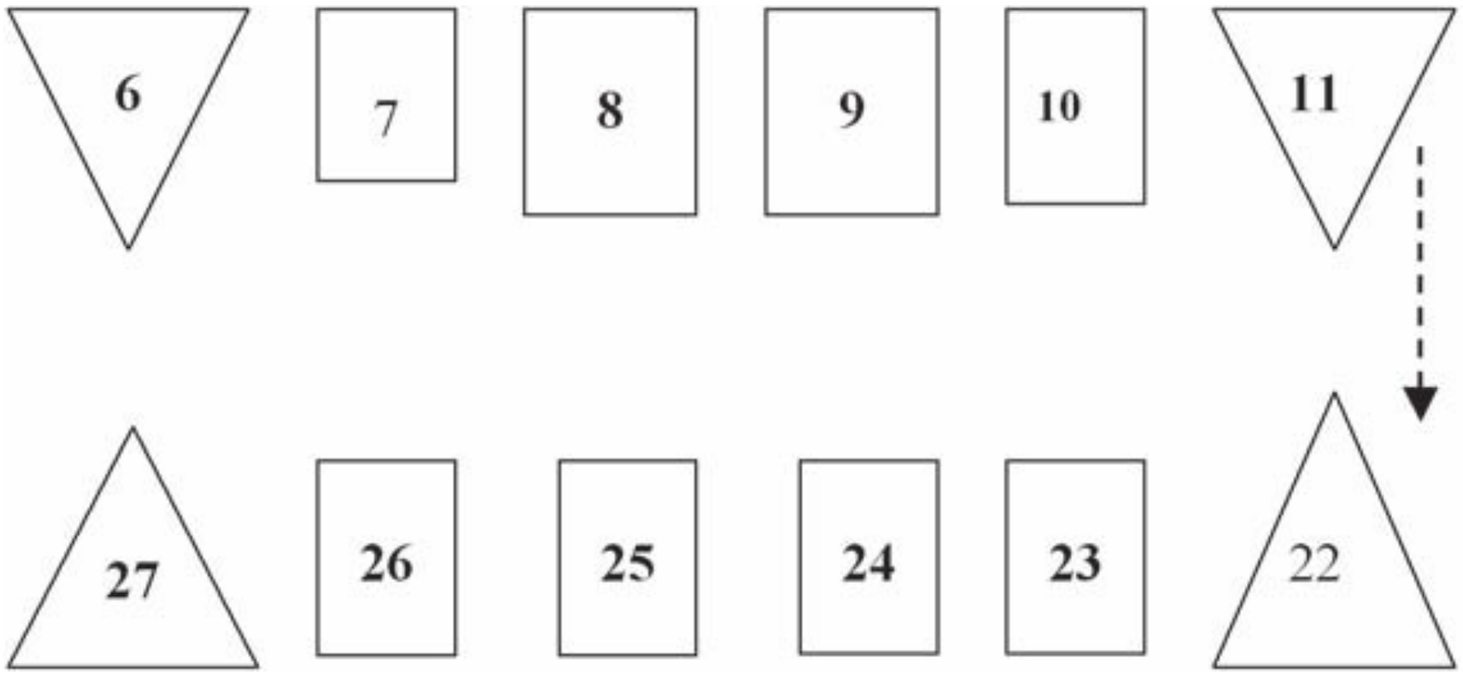


FIGURE 55-4 Easy tooth-numbering guide.
(Reused with permission from Buffington CW, Vallejo MC. A simple preanesthesia dental examination. Anesthesiology. 2006;104:212–213.)

Table 55-2
Patient-Specific Risk Factors of Dental Injury

Preexisting dental restorations (caps, crowns, bridges, veneers, root canals, and dental implants)
Preexisting periodontal condition (loose tooth or teeth)
Chipped, cracked, or brittle teeth
Age (young primary deciduous teeth, elderly)
Crowded anterior teeth
Isolated tooth or teeth

Table 55-3
Anesthesia-Specific Risk Factors of Dental Injury

General anesthesia
Endotracheal intubation
Difficult airway (Mallampati class 3 or 4, limited mouth opening, limited head extension, or limited neck movement)
History of difficult intubation
Oral endoscopy



FIGURE 55-5 Wrapping 8-0 suture around loose tooth.
(Reused with permission from Yasny JS. Perioperative dental considerations for the anesthesiologist. Anesth Analg. 2009;108:1564–1573.)

THE MANY CAUSES OF HOARSENESS IN AIRWAY MANAGEMENT

Hoarseness is a postintubation complication with several etiologies including laryngeal nerve injury, laryngeal edema, vocal cord granuloma, vocal cord polyp, vocal cord adhesion, vocal cord fracture, and arytenoid cartilage subluxation. The etiology of these complications can be manifold including acute trauma from endotracheal tube placement or pressure on the posterior larynx from the balloon or the endotracheal tube itself. Risk of intubation trauma include abnormalities of laryngeal anatomy, repeated attempt at laryngoscopy or intubation, perioperative endotracheal tube movement, acid reflux, or endotracheal tubes that are inappropriately large for the patient or have a high pressure cuff.[41] Acute laryngeal edema postextubation can be treated with nebulized racemic epinephrine. When persistent, this problem should be evaluated by the otolaryngology service, typically with fiberoptic laryngoscopy. Figure 55-6 shows an example of vocal cord bowing caused by trauma from an intubation.[42] The authors' presumed mechanism for this damage was the use of an oversized endotracheal tube that exerted pressure on the laryngeal mucosa and the recurrent laryngeal nerve causing subsequent deformation.

Damage to the arytenoid cartilage can occur during a routine or difficult intubation when the distal tip of the endotracheal tube displaces the arytenoid cartilage either anteriorly or inferiorly.[1] In particular, patients with a past medical history of systemic illness, including chronic renal insufficiency, Crohn disease, and acromegaly, who present with persistent hoarseness, sore throat, and dysphagia,



FIGURE 55-6 Vocal cord bowing is a risk of tracheal intubation.

(Reused with permission from Shimokojin T, Takenoshita M, Sakai T, et al. Vocal cord bowing as a cause of long-lasting hoarseness after a few hours of tracheal intubation. Anesthesiology. 1998;89:785–787.)

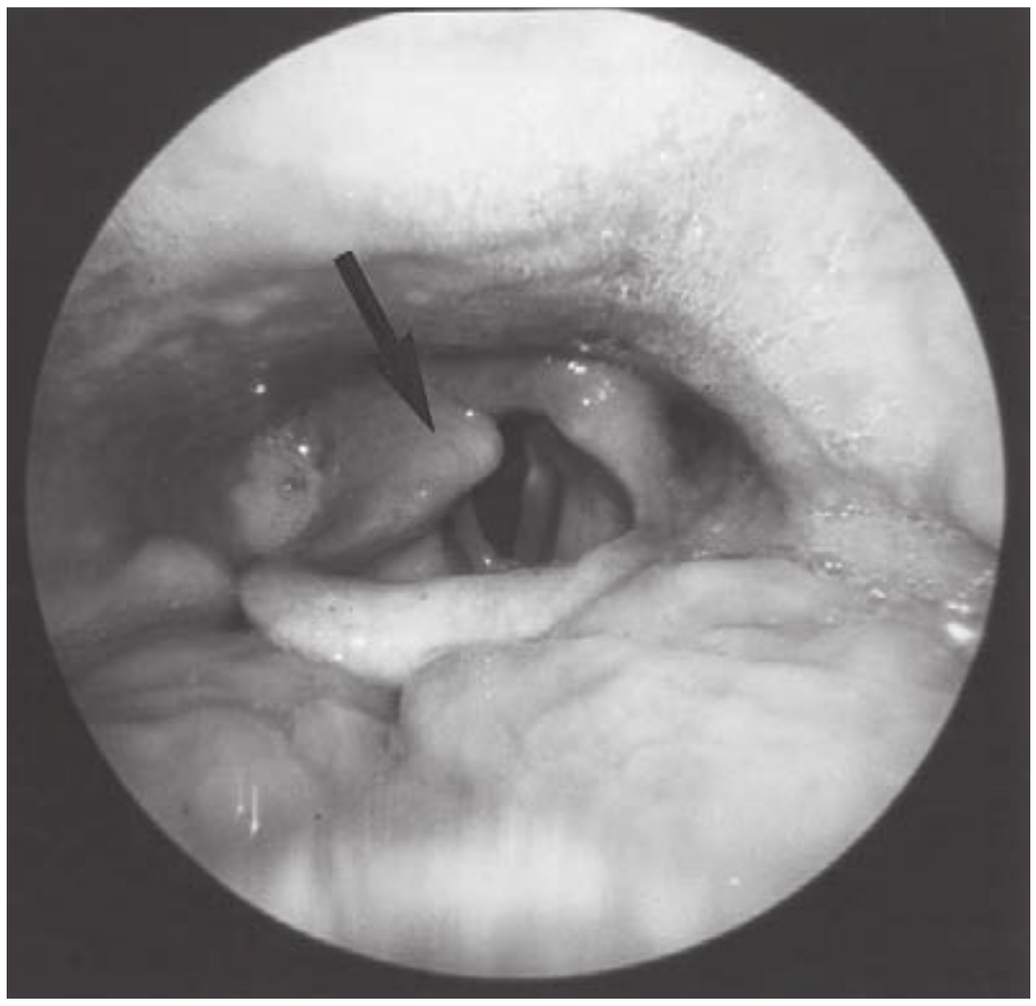


FIGURE 55-7 Arytenoid cartilage subluxation is a risk of tracheal intubation.

(Reused with permission from Paulsen FP, Rudert HH, Tillmann BN. New insights into the pathomechanism of postintubation arytenoids subluxation. Anesthesiology. 1999;91:659–666.)

should be evaluated for possible arytenoid cartilage damage (Fig. 55-7).[1,43] A study by Paulsen et al on the larynx of cadavers suggested an inapparent mechanism for arytenoid cartilage subluxation. Instead of the displacement arising from the initial trauma, the subluxation is due to the formation of fractures of the cricoarytenoid joint leading to the fixation of these cartilage pieces in an abnormal position.[43] In addition, one case report has described the posterior lateral displacement of the arytenoid cartilage by pressure from the shaft of a double-lumen endotracheal tube.[44] Arytenoid subluxation is a rare complication, occurring in only 0.023% of patients, but it has serious implications including possible permanent hoarseness and compromised airway protection.[45] Evaluation by the otolaryngology service would include indirect and direct laryngoscopy, CT scan, and electromyography of the larynx.

AIRWAY PERFORATION/ TRACHEOBRONCHIAL LACERATION AND RUPTURE

Tracheobronchial rupture is a rare complication of endotracheal intubation with an estimated incidence of 0.05% to 0.37%, though it is more commonly found in the setting of blunt chest trauma.[46–50] This is a life-threatening complication that may lead to respiratory failure and cardiovascular collapse from tension pneumothorax or tension pneumomediastinum. The risk factors associated with tracheobronchial rupture include operator experience, unanticipated difficult intubation, inappropriate use of a stylet, and overinflation of the endotracheal tube cuff.[51–53] A high level of suspicion should be maintained when a patient with the aforementioned risk factors acutely develops head and neck emphysema, hemoptysis, hypoxia, and elevated airway pressures. A patient who is suspected of tracheobronchial rupture requires an evaluation to visualize the site of injury.[52] The decision to pursue conservative or surgical management depends on the site of the tear and the patient's underlying medical condition; case reports have documented the use of conservative management for treating small uncomplicated tears in stable patients.[49,54,55]

PNEUMOTHORAX

Pneumothorax can be a complication of endotracheal intubation caused by direct trauma to the esophagus or airway, high airway pressure causing alveolar rupture, or extrathoracic trauma.[56–59] One of the two cases of esophageal perforation reported by Hilmi et al resulting in a pneumothorax (Fig. 55-8). An elevated peak inspiratory pressure greater than 40 cm H_2O is a widely accepted threshold

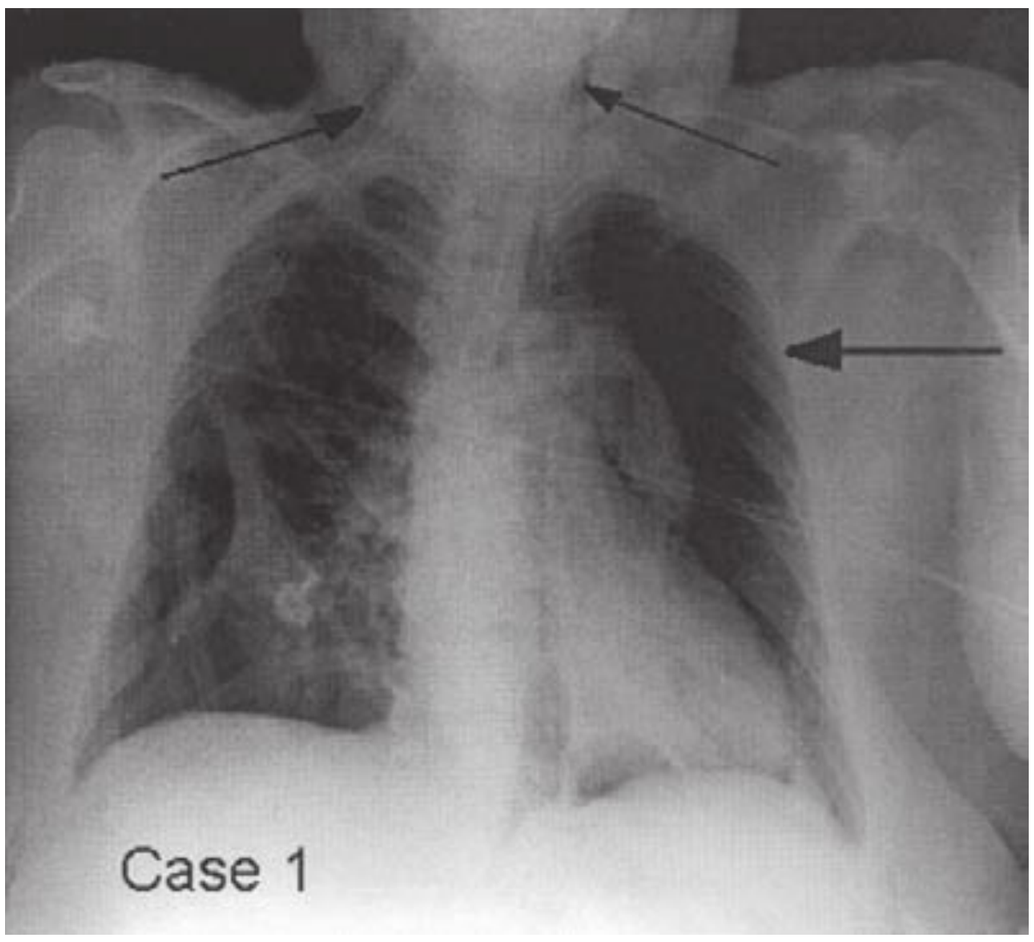


FIGURE 55-8 Subcutaneous emphysema and pneumothorax.

(Reused with permission from Hilmi IA, Sullivan E, Quinlan J, et al. Esophageal tear: an unusual complication after difficult endotracheal intubation. Anesth Analg. 2003;97:911–914.)

pressure for a patient to be at risk of a pneumothorax.[60] It is important to consider the possibility of a postintubation pneumothorax in the clinical setting of hypoxia, elevated airway pressures, unilateral breath sounds, and hypotension. If a tension pneumothorax is suspected because of persistent hypotension, a large-bore intravenous catheter should be inserted in the second intercostals pace in the midclavicular line before a chest X-ray is obtained.

COMPLICATIONS FROM PROLONGED INTUBATION

Prolonged tracheal intubation increases the patient's risk of laryngeal and tracheal damage because the endotracheal tube and its cuff resting on the mucosa of the posterior larynx create a pressure that may compromise mucosal blood flow as early as several hours after intubation, and the risk of further damage increases with prolonged intubation.[41] The endotracheal cuff pressure should be maintained at less than 30 cm H_2O to prevent tracheal pressure damage.[61] The initial mucosal damage presents as edema and hyperemia, which can progress to ulcerations and granuloma formation along the mucosa of the pharynx and the trachea.[41] The subsequent formation of scar tissue and strictures, depending on the location, may lead to vocal cord dysfunction or airway obstruction.[41] These patients demonstrate persistent hoarseness, dysphagia, and signs of airway obstruction which manifest as reduced flows on pulmonary function testing.[41] It is important to note that ulcerations that progress to tracheal erosions can form a tracheoesophageal fistula and/or tracheomalacia, both of which incur a significant risk of tracheal collapse.[41] A tracheostomy is usually recommended for a prolonged intubation that is expected to last longer than 2 to 10 days, in order to reduce the risk of laryngeal injury and the risk of ventilator-associated pneumonia from micro aspiration of oral secretions.[62]

CONCLUSION

Endotracheal intubation is so routine and safe that it is easy to assume that the intubation will have no lasting consequences. Usually that assumption is true, but an adverse event can still occur in the hands of a skilled practitioner during a routine intubation. Complications related to intubation are significant, and it is paramount that those who manage airways understand these risks. This chapter has outlined notable risks related to intubation with the goal of teaching providers how to prevent, predict, recognize, and treat complications.

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CHAPTER 56

Care of the Patient with a Surgical Airway: An Approach to Emergency Interventions

Elizabeth H. Sinz

SURGICAL AIRWAYS

Tracheostomy, tracheotomy, and cricothyroidotomy are surgically created airway openings directly into the trachea below the vocal cords. In many ways, the airway is greatly simplified because the upper airway has been circumvented; nevertheless, many physicians and other caregivers are stymied when they encounter a problem with a surgical airway. Understanding the anatomy resulting from the different surgical approaches and knowing how to manage some common complications can alleviate the fear and frustration associated with airway compromise in this patient population.

A tracheostomy, or tracheal stoma, is most often created when a patient undergoes a laryngectomy. In this case, the trachea is diverted to the neck, and there is *no connection* between the trachea and any upper airway structures. The only way to access the lungs of these patients is via the tracheal stoma (Fig. 56-1 A and B).

A tracheotomy is a hole in the trachea that is made surgically through the front of the neck. The patient's upper airway remains in continuity with the trachea, although depending on the reason for the procedure, the upper airway anatomy may or may not be normal. There are two ways to access the lungs of these patients: either through tracheotomy or through the upper airway (Fig. 56-2 A, B and C).

In an airway emergency, the trachea may be surgically approached through the cricothyroid membrane, using a procedure called a cricothyroidotomy. (See Chapters 36, Cricothyrotomy, and 37, Wire-Guided Cricothrotomy) This creates an opening into the airway through the neck and cricothyroid membrane just below the vocal cords. This is a temporary airway, typically created under emergency conditions to provide oxygen to the patient until a formal tracheotomy or other airway access can be obtained, although this is somewhat controversial.[7] The upper airway of the patient is intact, but the reason for requiring an emergency surgical airway is often due to abnormal or injured upper airway structures, so it may be very difficult or impossible to approach the trachea from above.

Although these different approaches may not seem complicated, failure to recognize how the trachea has been surgically altered can lead to poor decision making in an airway crisis. The most likely problems one will encounter differ somewhat with each type of surgical approach.

OXYGENATION AND VENTILATION IN A PATIENT WITH A TRACHEOSTOMY

A tracheostomy generally requires no equipment, such as a tube, to remain patent. Patients often wear a cloth cover to preserve their appearance and protect their airway from dust and debris. Healthcare providers must be careful not to overlook the patient's actual airway in a medical emergency. Oxygen given via nasal cannula or face mask, for example, will not reach the patient's lungs; supplemental oxygen must be administered over the tracheal stoma to be effective.

Positive pressure ventilation provided by a normal bag-valve-mask apparatus to the face will only inflate the patient's stomach. If a patient with a tracheostomy requires positive pressure ventilation there are two options: (1) application of a small mask to the neck over the tracheal opening, or (2) insertion of a cuffed tube (either an endotracheal tube or a tracheotomy tube) into the ostomy with positive pressure via this tube.

OXYGENATION AND VENTILATION IN A PATIENT WITH A TRACHEOTOMY

A tracheotomy will typically close over time unless there is a tube or a plug in place to keep it open. People with a tracheotomy tube who are breathing spontaneously may be breathing through their nose and mouth or through their tracheotomy or both. If in respiratory distress, the patient may be experiencing a blocked or partially blocked airway (upper or lower) or they may need assistance with ventilation due to poor ventilatory mechanics or acute illness (ie, pneumonia or pulmonary edema). The underlying cause of respiratory distress should be determined quickly so that the proper treatment can be initiated early.[3]

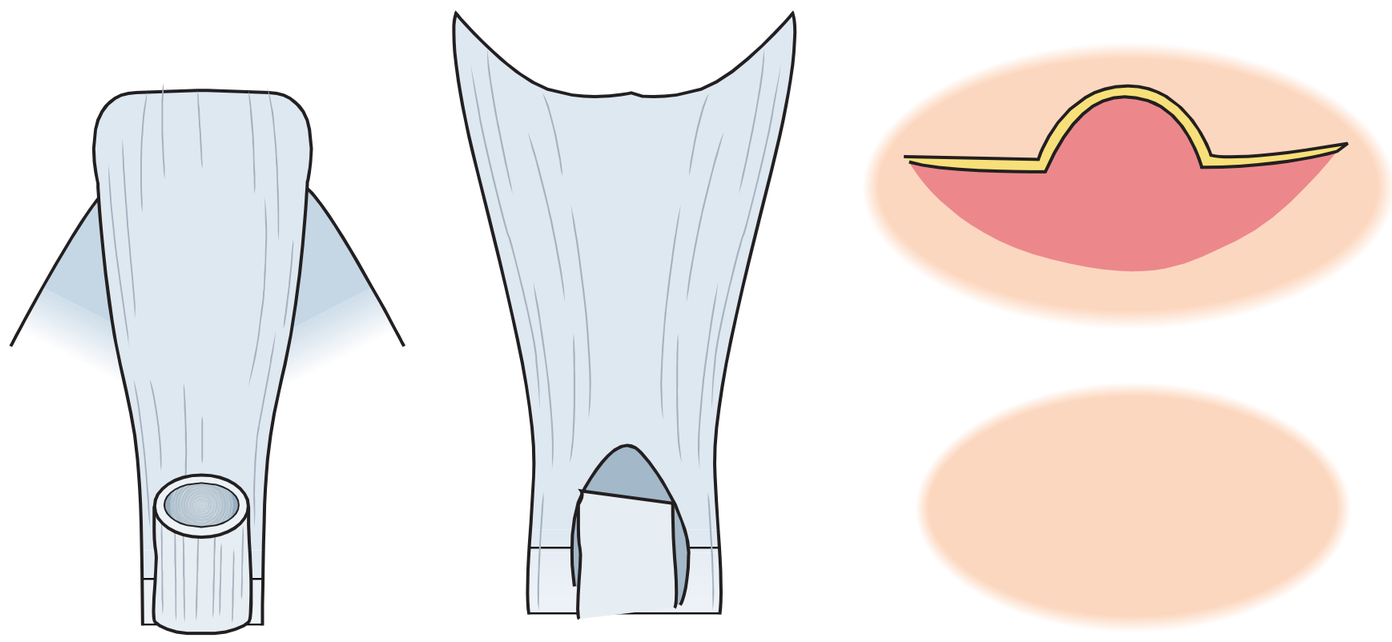
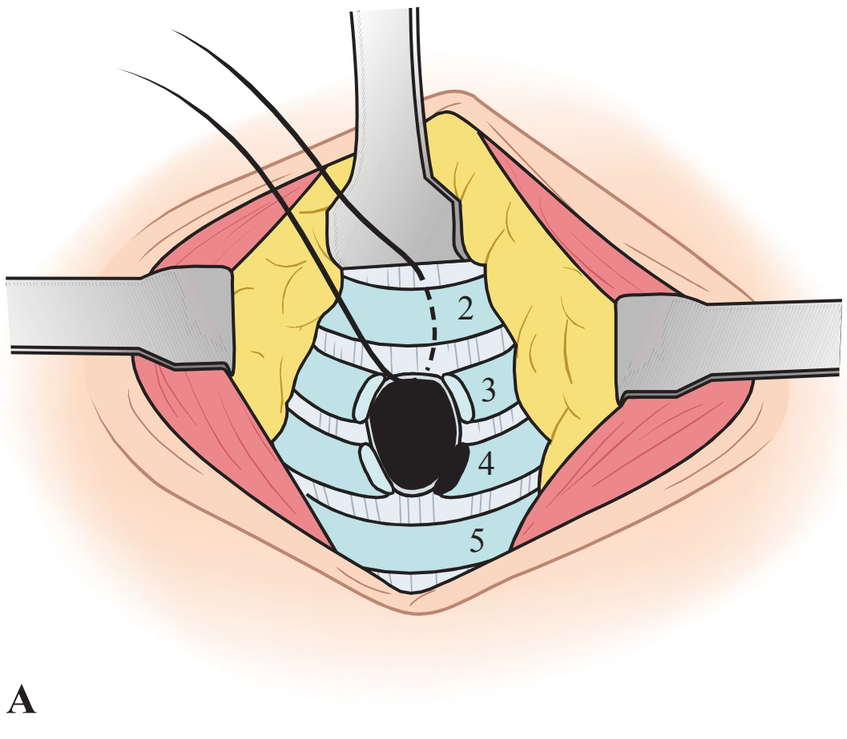


FIGURE 56-1 **A** Tracheostomy: surgical opening into the trachea through the neck, with the tracheal mucosa being brought into continuity with the skin, often permanent. **B** Patient with a tracheostomy. This patient has undergone a laryngectomy and has no connection between his upper airway structures (nose and mouth) and his lungs. Note the lower position on the neck compared with a typical tracheotomy and the lack of a tracheotomy tube, plug, or other stent to maintain patency.

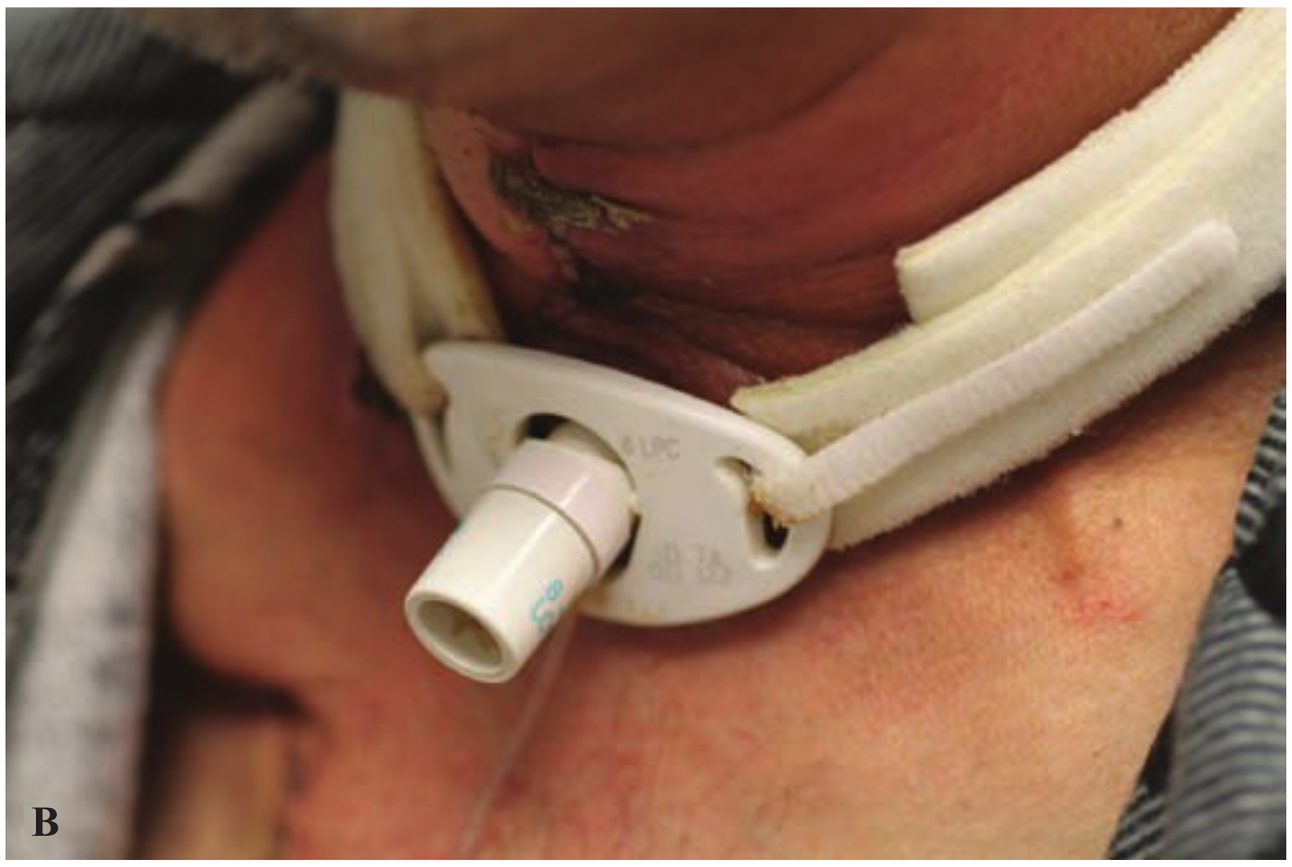
CUFFED TUBES VERSUS NONCUFFED TUBES

Patients who require positive pressure ventilation through a tracheotomy tube should have a cuffed tracheotomy tube in place. These tubes have a pilot balloon attached to the cuff that hangs down on the outside (Fig. 56-3). It is possible for these cuffs to rupture or leak and no longer provide a seal between the tube and the trachea. More commonly, the patient who no longer requires positive pressure ventilation will have the cuff deflated or a new tube may be placed that has no cuff. These long-term tubes are plastic or metal and may have fenestrations to allow air to flow through as well as around the tracheotomy tube, thereby allowing breathing through the vocal cords and upper airway, and making normal speech possible by externally occluding the tube.[2,11]

Without the seal provided by a cuff, positive pressure ventilation will be ineffective through a tracheotomy tube. If a patient develops respiratory compromise requiring positive pressure ventilation, either with a bag-valve apparatus or a ventilator, the cuff must be inflated to create a seal. If the tube in place is fenestrated, the inner cannula must be inserted to occlude the fenestration. A third option is to occlude the opening of the tracheotomy tube and apply positive pressure from above using a face mask. If none of these options are viable, the tracheotomy tube should be removed and a cuffed tube should be inserted either through the hole in the neck or through the upper airway using traditional or alternative intubation techniques.



A



B



C

FIGURE 56-2 **A** Tracheotomy: incision or opening of the trachea with no implication of permanence. **B** Patient with a tracheotomy tube in place. This patient has an incision through his neck into his trachea, but his upper airway remains intact. **C** The tracheotomy tract is mature and remains open when the tracheotomy tube is removed.



FIGURE 56-3 A cuffed tracheotomy tube and its components: Outer cannula with flange; Inner cannula; Obturator (to ease placement, then removed)

POTENTIAL COMPLICATIONS

It is helpful to know the common causes of respiratory compromise in patients with surgically created airways.[4,6,8,10,11] Early complications of tracheotomy include subcutaneous or mediastinal emphysema and pneumothorax. Because many of the patient's protective functions are compromised due to bypass of the upper airways, continued insertion of a foreign body, and interruption of ciliary clearance and impaired cough, patients with chronic surgical airways are at increased risk of pulmonary infections A chest X-ray is often a helpful diagnostic tool, but should not delay therapeutic interventions in a true emergency.

Occlusion can occur as the result of equipment problems, foreign body aspiration, or from the patient's own secretions or blood. If a foreign body is aspirated, it should be removed if possible; if this cannot be done and the patient is in grave distress, pushing the object distally may be lifesaving. If the tube is intentionally occluded by a mechanical plug or a speaking valve (passy muir valve), removing this may alleviate the problem.

Dried blood or secretions can build up inside or around the tip of the plastic or metal tube and can be difficult to dislodge, even with suction. In addition, the continual irritation of the artificial airway can lead to granulation tissue formation, often at the tip of the tube, which can eventually cause a partial or total obstruction.[11] This can sometimes lead to a "ball-valve" effect that can be particularly problematic, leading to difficulty exhaling.

A suction catheter should be used to remove the material blocking the airway; sometimes it may push the blockage aside or down. Determining the cause of the patient's problem is easiest with a bronchoscope passed through the tube to see what is causing the blockage.[1,5,9] Occasionally an X-ray will reveal a foreign object; however, if the occlusion is not due to radiopaque material the study may not be helpful.

Inadvertent decannulation is a life-threatening complication. If there is no air flow through or around the tube, the circumstances require immediate action or the patient will asphyxiate. In this case, the tube may be completely obstructed or it may have become displaced in a false passage between the skin and the trachea. This is particularly common in a patient with a recent tracheotomy in a thick or short neck.[9] In this case, the suction catheter will not pass and attempts to ventilate will be met with very high resistance. The tracheotomy tube should be removed immediately and replaced with a patent tube either through the tracheotomy hole in the neck or via the upper airway using traditional or advanced intubation techniques.[11] New tracheotomies will often have stay sutures attached to the tracheal cartilage to assist with replacing the tracheotomy tube. If tracheal intubation is not possible, mask ventilation with a face mask, or alternative advanced airways such as a laryngeal mask airway or esophageal airway (ie, King tube or Combitube) should be attempted. Effective positive pressure ventilation from above may require occlusion of the tracheotomy hole with a finger. A retrograde wire passed through the tracheotomy hole that passes out of the upper airway may assist with placement of an ETT from above. (See retrograde wire chapter.)

A patient with a tracheostomy following a laryngectomy has no connection between his nose or mouth and his trachea and lungs. Any ventilation approach via the upper airway will be unsuccessful.

In all cases, ventilation is best confirmed with continuous waveform (one word) capnography. Bilateral breath sounds must be discerned with care because the likelihood of passing a tube too deep and entering one of the

mainstem bronchi is increased due to the relatively short distance between the tracheotomy and the carina. Other indications of successful airway placement include chest rise and patient response to ventilation.

BLEEDING

Bleeding can occur within hours or days of placement of a surgical airway, or it can occur much later due to erosion of the tube into vascular structures or from trauma from suctioning.[6,8,9,10] The most immediate problems with bleeding are airway or tube obstruction due to clots and "drowning" due to blood filling the lungs. It is uncommon, but possible, for a patient to exsanguinate from upper airway bleeding.[11] If the bleeding is from the upper airway, it may be helpful to place the cuff distal to the bleeding site to keep the blood from entering the lungs. This can be achieved by placing a longer tracheotomy tube or by replacing the tracheotomy tube with an endotracheal tube. As the upper airway may be filled with blood, this maneuver may be quite challenging and should only be attempted by an airway expert, preferably in a controlled environment such as the operating room. If the bleeding is in the vicinity of the tracheotomy tube, overinflation of the cuff may tamponade the bleeding until definitive surgical treatment can be obtained.

Clots should be aggressively suctioned, and though use of a bronchoscope may be helpful to locate the clot, the suction port of a bronchoscope may not have adequate diameter to successfully remove large clots. A directed catheter will usually be more effective. Any serious or ongoing bleeding should be addressed surgically to explore and control the source.[11]

AIRWAY EMERGENCIES IN THE PATIENT WITH A SURGICAL AIRWAY

Finding a patient in acute respiratory distress is always scary; when the patient has a problem with an unknown or poorly understood artificial airway, the tension increases exponentially.

> *'The definition of insanity is doing the same thing over and over and expecting a different result." Source unknown*

Approaching the problem in a methodical way will increase the chances of a successful outcome. Calling for specific, specialist help early is critical, but it may not be possible to wait for help to arrive before acting. Providing oxygen to the patient is the primary goal. A suction catheter or bronchoscope can be helpful for both diagnosis and sometimes treatment. Act quickly, stay calm, and tailor subsequent interventions based on the information you obtain from each maneuver. Avoid repeating unsuccessful maneuvers.

With knowledge of the patient's anatomy after a surgical airway procedure, the best approach for alleviating respiratory distress can be quickly ascertained.

CONCLUSION

There are a variety of surgical approaches to the airway. Understanding the nature of the surgery, the anatomy of the patient's airway, and whether or not a connection remains between the upper airway and the lungs is imperative when assessing respiratory complaints or emergencies in patients with a surgical airway. Other common postoperative complications include dislodgement, bleeding, obstruction due to clot, mucous, or foreign body, and granuloma tissue formation.

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